Lawrence Berkeley National Laboratory

Safety Assessment Document (SAD) for the Advanced Light Source *(Rev. 7)*

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Signature Page for Rev. 7 of the ALS SAD

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REVISION RECORD

Date	Rev. No.	Revision Description
September 2008	6	Added Top-Off Mode. The major operational change was the injection of electron bunches into the storage ring with the beamline shutters open. New interlocks and configuration control of front-end apertures have been installed to ensure safe operation and these carried over to a revised Accelerator Safety Envelope. Other changes in the document were organizational changes to the ASE chapter and explicit, formal hazard analysis of the radioactive materials used at the ALS.
January 2009	6	Administrative Update made to the Accelerator Operations Envelope. The old limit for the storage ring current was 500 mA. With full injection now at that value, the limit needed to be raised to 550 mA. This value is still well below the current limit of 780 mA implied in the 1000 J limit of the Accelerator Safety Envelope.
April 2009	7	General revision involving significant changes throughout document. Restructured the hazard analysis to conform to current DOE/LBNL standards (systematic review, what/if scenarios, before/after risk analysis, explicit identification of credited controls, etc.). Reorganized and shortened sections to make consistent with new LBNL standard.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF ILLUSTRATIONS

SECTION 1. INTRODUCTION

This Safety Assessment Document (SAD) for the Lawrence Berkeley National Laboratory (LBNL) Advanced Light Source (ALS) provides the necessary information and analyses to assure that the operation of the ALS can be conducted in a manner that produces minimal risks to the health and safety of LBNL employees, visiting scientists, and the public, as well as adequately protect the environment.

LBNL Building 6, which was originally constructed to house the 184-Inch Cyclotron, was extensively remodeled and significantly enlarged for the ALS, a synchrotron-radiation source of X-ray and ultraviolet radiation. As a national user facility, the ALS is open to visiting researchers and to LBNL staff, who use this radiation for basic and applied scientific and technological investigations, including structural and spectroscopic studies of gases, liquids, and solids.

1.1 OBJECTIVE AND SCOPE

This SAD has been prepared in accordance with DOE Order 420.2B Safety of Accelerator Facilities to describe the physical and administrative controls that will ensure the safe operation of the ALS at LBNL. DOE Order 420.2B specifies that the SAD must "identify hazards and associated onsite and offsite impacts to workers, the public, and the environment from the facility for both normal operations and credible accidents."

The safety of the ALS is analyzed, reviewed, and documented at the SAD level commensurate with its classification as a low-hazard facility. The safety analyses documented in this report demonstrate that ALS construction and operation are consistent with a complex facility with no more than minor onsite and no more than negligible offsite impacts, as defined in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B. Thus the level of on site impact is such that permanent health effects or environmental damage are not expected (Criteria: minor injuries; 1 to 25 rem effective dose equivalent), and the level of offsite impact is such that the potential for health effects or environmental damage is very slight (Criteria: injuries requiring only superficial professional medical attention; < 1 rem effective dose equivalent).

As recommended by DOE Guide 420.2-1, the analysis is not duplicative of other activities carried out in the development of a facility's overall environment, safety, and health program such as the development of Work Smart Standards and the implementation of a site-specific ISM system. This SAD addresses those hazards that are not routinely encountered and accepted in the course of everyday living by the vast majority of the general public.

1.2 FACILITY PURPOSE

The ALS has been constructed in the Original Laboratory Site area of LBNL on the site of the historic 184-Inch Cyclotron, which was decommissioned and disassembled. To make room for the ALS, the original cyclotron building (Building 6) was renovated, and a new 61,000 square-foot annular addition was constructed. The new building houses a 1.9-billion-electron-volt (1.9-GeV) electron storage ring and its associated injector complex for the generation of synchrotron radiation in the X-ray and ultraviolet regions of the electromagnetic spectrum. The radiation will be guided by up to 60 insertion-device and bend-magnet beamlines to experimental areas around the outside of the storage ring. Each beamline may have more than one branch with separate experimental stations. In addition there are two electron beam lines (the Beam Test Facility and the Beam-To-Storage ring beamline) for experiments involving the interaction of relativistic electron beam with plasmas, laser beams, and electromagnetic cavities.

Physicists, chemists, materials scientists, biologists, engineers, and other researchers use the radiation to investigate the structure and composition of matter in its varied gas, liquid, and solid states. In addition to the radiation itself, the ALS provides the necessary structures and support systems to carry out this type of research. Responsibility for the beamlines and the experimental equipment is divided between the ALS and those doing the research, who will come from LBNL, other DOE and federal laboratories, private industry, and universities.

1.3 FACILITY DESCRIPTION AND OPERATION SUMMARY

The ALS is a national user facility for the production of high-brightness and partially coherent X-ray and ultraviolet synchrotron radiation [ALS, 1986, 1989a]. A DOE-funded construction project with a total estimated cost (TEC) of $99.5 million, the ALS was completed on schedule in April 1993. Administratively, the ALS resides within the Advanced Light Source Division of LBNL.

The ALS consists of a linear accelerator and a booster synchrotron (collectively known as the injector complex) and an electron storage ring, photon beamlines from insertion-device and bend-magnet sources, and associated experimental facilities. The ALS site covers a sizable, flat hilltop with good foundation conditions, centrally located within LBNL. The original Building 6 provided approximately 20,000 square feet of floor space, which is being used for the linear accelerator and booster synchrotron. The storage ring, beamlines, and experimental facilities required the construction of a 61,000 square foot addition to Building 6. The addition consists of a 30-foot high steel-framed structure on new concrete footings with a heavy-duty concrete floor slab.

Included in the second floor of building 6 is approximately 33,000 square feet for office, light laboratory space and support facilities for beamline assembly at the ALS. Support facilities in the ALS building include a visitors' reception area, conference rooms, utility/storage space, and toilet facilities. Building 80 (adjacent to the Building 6 addition) houses the ALS control room, offices, electrical and mechanical shops, and a conference area. It is accessible via a connecting door.

Operational activities fall into three categories: (1) generation of a 1.9-GeV electron beam by the linac and booster synchrotron and storage of the beam for several hours in the storage ring, (2) use of the X-ray and ultraviolet radiation by LBNL and visiting scientists for the research activities described in Section 1.2, and (3) use of the electron beamlines to support R&D activities of various LBNL and visiting scientists.

Operation of the injector accelerators and storage ring is accompanied by the generation of bremsstrahlung and neutron radiation for which shielding is provided. Exposure of LBNL and visiting scientists to X-rays and other ionizing radiation is prevented by fixed in-place shielding, interlocked enclosures, and active radiation interlocks. The radiation shielding design is based on the dual design goals of limiting the radiation exposure to the general public, users, and the majority of ALS staff to less than 10 mrem/year, and limiting occupational exposure to selected ALS staff to less than 250 mrem/2000-hour worker year. The shielding design allows the facility to achieve the DOE As Low As Reasonably Achievable (ALARA) radiation design objectives.

Use of the X-ray and ultraviolet radiation by LBNL and visiting scientists may be accompanied by the introduction of flammable, toxic, biologically active, and radioactive materials in gaseous, liquid, and solid form. Volumes of hazardous materials will not exceed applicable building and fire code limits, and required venting and containment systems will be provided. In some cases where the hazardous material is the sample to be investigated and is present only in minute quantities, the material will be transported and studied only in sealed containers.

All beamline apparatus and experimental equipment, including lasers used in conjunction with synchrotron-radiation experiments, are subject to a mandatory safety evaluation before installation and will be operated in accordance with published codes and standards.

SECTION 2. SUMMARY AND CONCLUSIONS

The ALS safety analysis was prepared in accordance with the guidance provided in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B.

The methodology used to perform the ALS safety analysis is described in detail in Section 4. The process began with a review of proposed ALS operations and research activities. Using the information obtained, a listing of credible hazards associated with those proposed ALS activities was developed. These hazards were evaluated to determine if they were accelerator-based hazards or if they were standard industrial hazards. Accelerator hazards were evaluated in detail, but standard industrial hazards were only evaluated in detail if they could be initiators to an accelerator event. Lastly, natural phenomena were also considered.

This subset of hazards was then further analyzed to assess associated risk. Each event analysis included determining the initiating occurrence, and its possible probabilities and consequences. Overall risk was determined using a standard matrix approach. Risks that were 'Negligible' or 'Low' were judged to be acceptable, while 'High' or "Moderate' risks were judged to be unacceptable. Events with unacceptable risks required mitigation.

Next, the controls that either reduce the probability of these events or mitigate the consequences were catalogued. Those that were used to reduce the levels of risk to acceptable levels are the credited controls and are defined in the Accelerator Safety Envelope.

The results of this analysis demonstrate that there is reasonable assurance that ALS operations, as controlled by the Safety Envelope described in Section 5 in accordance with the Hazard Analysis in Section 4 of this SAD, will be conducted in a manner that will limit risks to the health and safety of the public and employees to a "low level" and will adequately protect the environment. In particular, the results showed that the ALS facility can be operated within the risk envelope for complex facilities with no more than minor onsite and no more than negligible offsite impacts, as defined in DOE Guide 420.2-1 Accelerator Facility Safety Implementation Guide for DOE O 420.2B.

SECTION 3. DESCRIPTION OF SITE, FACILITY, AND ORGANIZATION

3.1 SITE DESCRIPTION

LBNL is centrally located in the greater San Francisco Bay Area and is situated on the western slope of the Berkeley Hills. The Laboratory overlooks the Berkeley campus of the University of California and San Francisco Bay on land within the boundaries of, and leased from, the University of California. The following sections characterize the features of the ALS site [DOE, 1989; Keller, 1987; Harding-Lawson, 1983].

3.1.1 Site Location

The site for the ALS is within and adjacent to the original Building 6. This building, whose construction was begun in 1940 and completed in 1942, was the first of approximately 30 buildings to be constructed in the so-called Original Laboratory Site of LBNL. The site is centrally located within LBNL. It is close to electromechanical and mechanical technology machine shops and technician facilities, as well as the main LBNL mechanical shops. The site is also adjacent to LBNL’s fire station and to the Advanced Materials Laboratory (Building 2). An adjacent older structure, Building 80 provides space for ALS activities, and is included in this SAD. Figure 3-1 shows the LBNL site and Figure 3-2 shows the ALS site.

3.1.2 Physiographic Setting

The Original Laboratory Site covers a sizable, flat hilltop area that commands a view of most of San Francisco Bay, including the San Francisco-Oakland Bay and Golden Gate Bridges, and of much of the surrounding urbanized areas of Alameda, western Contra Costa, San Francisco, San Mateo, and Marin Counties. The land around the site slopes downward, except on the northeast, where it slopes upward. The ALS site is toward the southwest corner of this area. Cut areas near the Advanced Materials Laboratory are supported by new retaining walls.

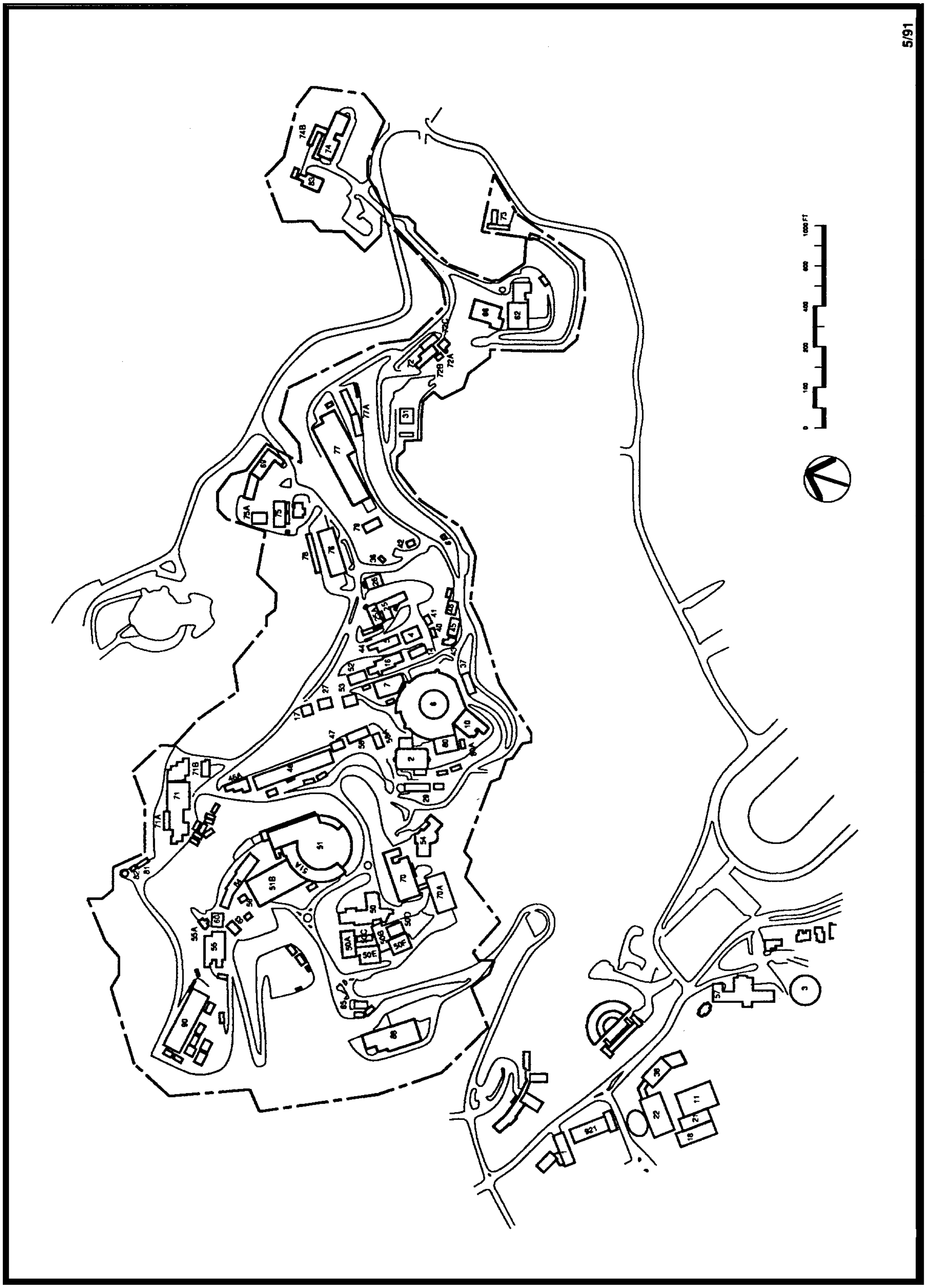

Figure 3-1. LBL site map.

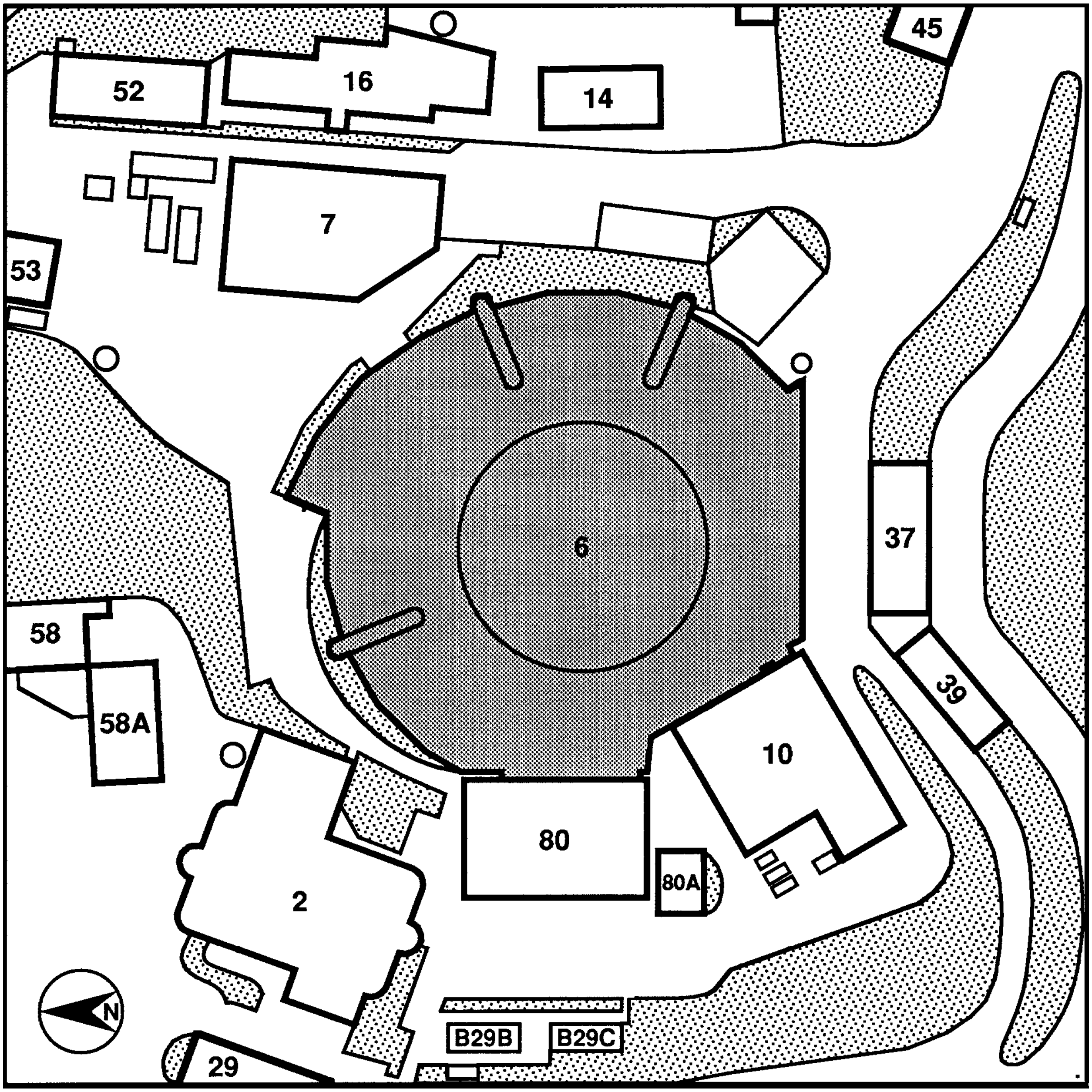

Figure 3-2. Advanced Light Source site, ground level.

3.1.3 Geology and Seismicity

The ALS site is located in the Berkeley Hills, which consist of a series of northwest-trending synclines and anticlines cut by numerous faults. The rocks are of marine, terrestrial, and volcanic origins. Differential erosion of soil and rock materials has created a diverse topography in the area. The bedrock formations are close to the surface and consist of volcanic basalt and site flows, pyroclastic tuff beds, and a sedimentary agglomerate (i.e. clayey siltstone).

Active faulting and crustal deformation continues in the area at the present time. The closest major fault lines are the Hayward Fault, which passes about 3500 feet to the southwest of the site, the Calaveras Fault, which passes 12 miles to the east of the site, and the San Andreas Fault, which passes 18 miles to the west of the site. The maximum credible earthquake postulated for the site would occur on the Hayward Fault and would have a Richter magnitude between 6.75 and 7.25 [LBNL, 1992a, Chapter 23].

3.1.4 Soils

The bedrock at LBNL is generally relatively weak and weathers deeply, thereby producing a thick colluvial soil cover. The bearing capacity of colluvial soil is relatively low, and foundation design usually requires consideration of the potential for shrinking and swelling. In addition, ancient land-slide deposits of variable dimensions are present throughout LBNL, as are areas covered by landfill placed during site grading. The northwestern corner of the ALS site is one of these areas. Overall the foundation conditions at the ALS site are satisfactory.

3.1.5 Hydrology

The ALS site is located on a ridge that divides the Strawberry and Blackberry Creek Watershed areas on a naturally flat area that interrupts the otherwise upward sloping hillside. The site is approximately 890 feet above sea level, which precludes the ocean or water table from having effects on the site. In addition, storm sewers are provided with about 900 cfs capacity, so that buildup of rainwater from storms will not affect the site.

3.1.6 Climate

LBNL is exposed to air flow from the Pacific Ocean through the Golden Gate and across San Francisco Bay. The marine influence keeps seasonal temperature differences relatively small.

Sunshine for the year averages between 65 and 70 percent of the total insolation possible, and average daytime cloudiness is about the same in summer as in winter. Except for laboratories with special temperature stability requirements, LBNL buildings are generally not air-conditioned.

3.2 SITE AND FACILITY DEMOGRAPHY

In 1992, LBNL had approximately 3000 full-time employees and 895 part-time employees (mostly students or staff with joint appointments on the UC Berkeley campus), as well as more than 1615 guest scientists.

During operation of the ALS, approximately 200 staff will be required to support and operate the facility. Up to 60 beamlines will be fully developed, and a maximum of about 150 users are on site at any one time, of whom about 20 percent are LBNL employees.

3.3 FACILITY DESCRIPTION

The ALS is a national user facility primarily for the production of high-brightness and partially coherent X-ray and ultraviolet synchrotron radiation. The ALS facility consists of an accelerator complex, a complement of beamlines and associated experimental areas, and a building (Building 6) to house this equipment. The following sections provide a description of the ALS layout, the accelerator complex, the beamlines, the experimental areas, as well as utility systems. Safety systems are described in Section 3.

3.3.1 Facility Layout

The ALS is located in the Building 6 area of the LBNL site. The-original Building 6, which was roughly circular with a high, domed roof, provides approximately 20,000 square feet of floor space. This space is being used for the linear accelerator and booster synchrotron. The storage ring, beamlines, and experimental facilities required the construction of a 61,000 square foot addition to Building 6. Support facilities for operations personnel include a visitors' reception area, utility/storage space, and toilet facilities. Figure 3-3 shows the ALS facility layout. Figure 3-4 shows the elevations of the ALS building. The 30-foot height of the addition includes 33,000 square feet of office and light-laboratory space on the second-floor structure over the experimental areas.

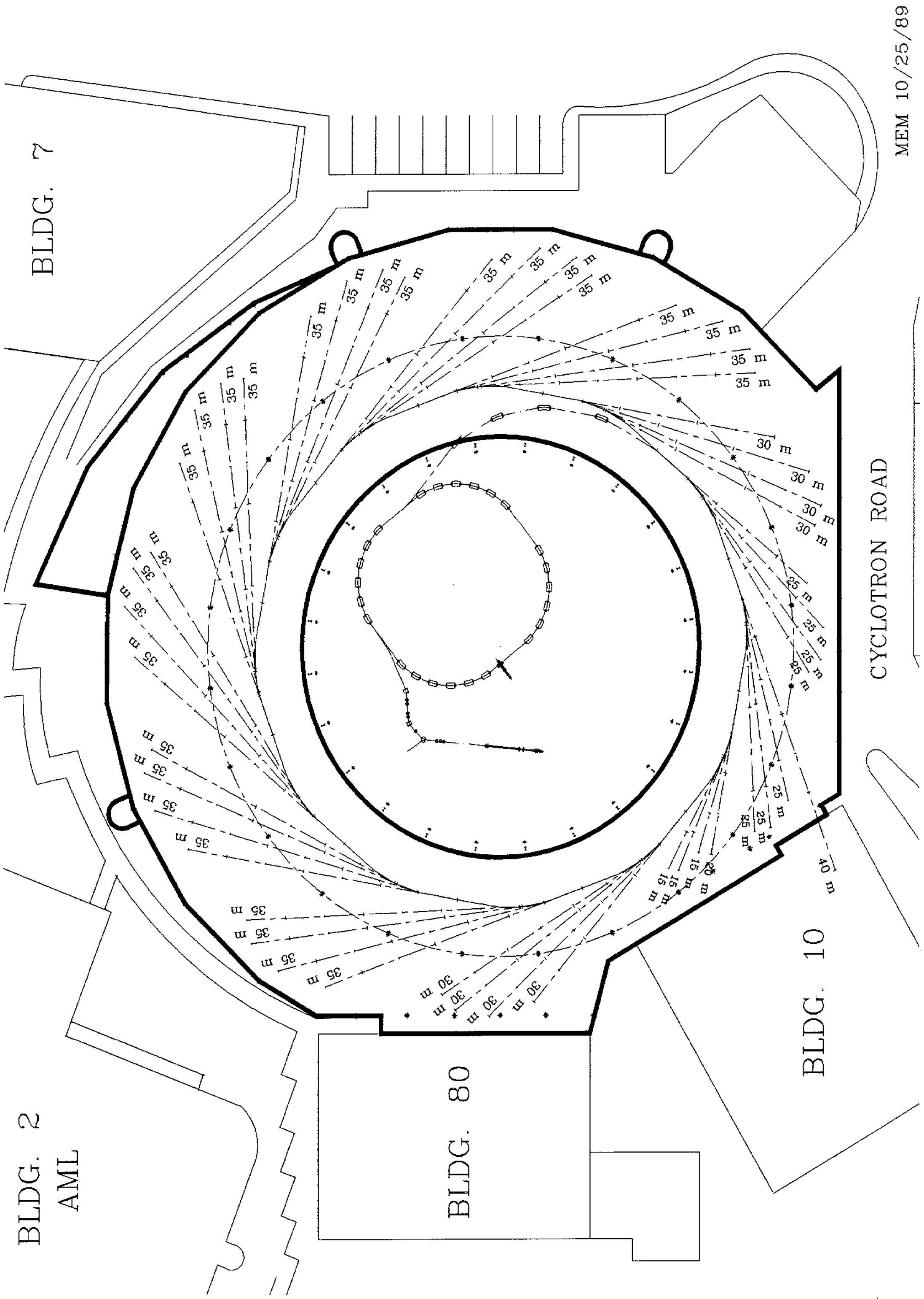

Figure 3-3. **Layout of the Advanced Light Source facility showing the linac, booster synchrotron, electron storage ring, and photo beamlines within the expanded** Building 6.

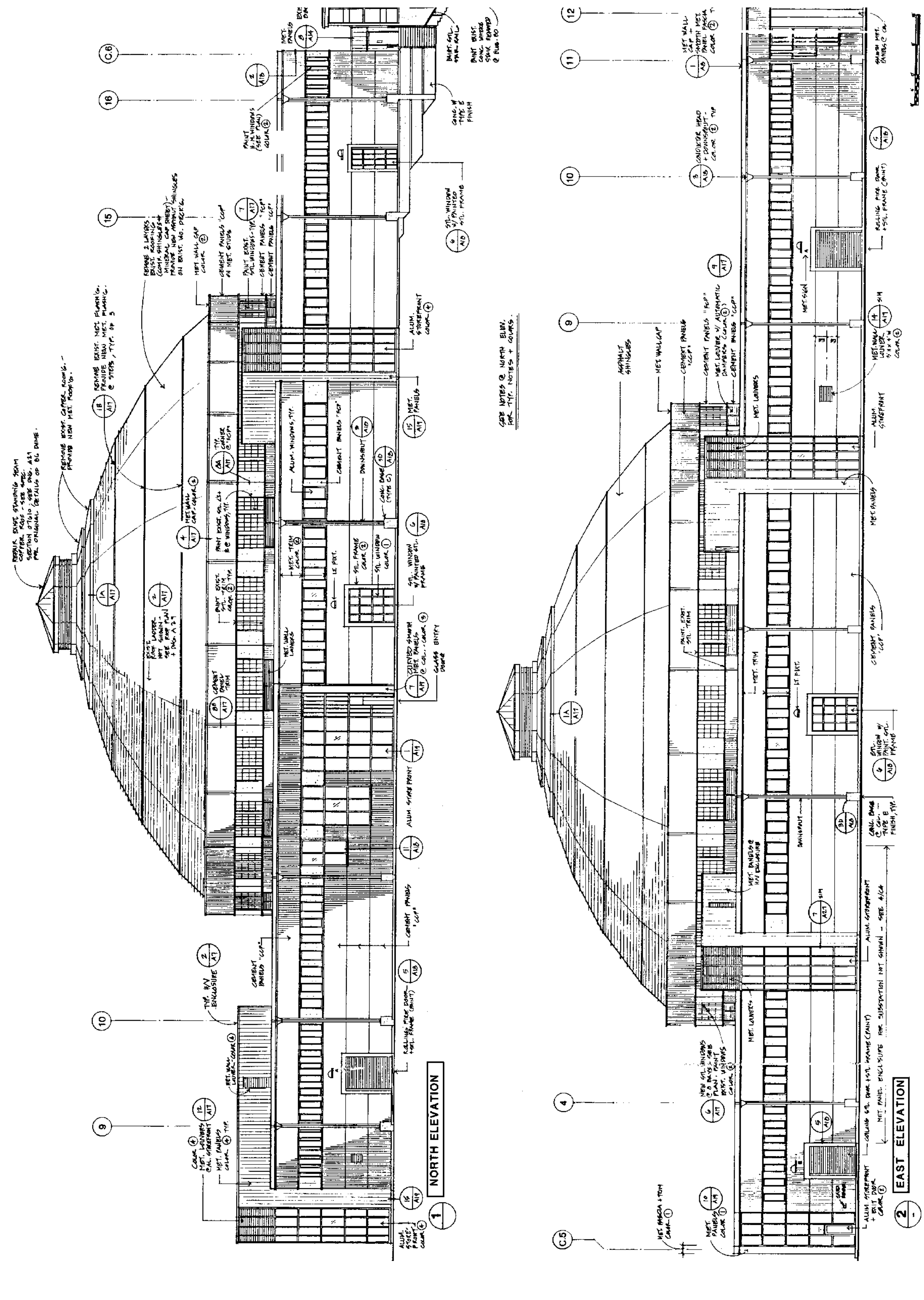

Figure 3-4. Elevations of the Advanced Light Source facility.

Buildings 80 immediately adjacent to the ALS has been modified only to the extent of window and door removals and their replacement with matching fire-rated wall materials where they are common with the new-addition walls. There is a seismic gap between the ALS and this building. The Building 6 area is surrounded on three sides by roadways and service-vehicle parking. Roadways around the site have been improved and some close-in parking has been provided.

Included in this SAD, Building 80 houses the ALS control room, staff offices, electrical and mechanical shops, some laboratory space, and a conference area. This building, which predates the ALS, comprises a basement, a main floor, and a second floor.

3.3.2 Utilities

Potable supply water and sanitary sewer wastewater treatment services for LBNL is provided by the East Bay Municipal Utility District (EBMUD). Natural gas and electricity are provided by Pacific Gas and Electric Company (PG&E).

The EBMUD water system serves about 1.3 million people in a 331 square-mile service area of Alameda and Contra Costa counties. EBMUD supplies water primarily from large-capacity reservoirs in the Sierra Nevada foothills. On average, 90 percent of the water delivered by EBMUD comes from the Mokelumne River watershed, with the remaining 10 percent originating as runoff from local watersheds within the service area. Water from the foothills is transported via 90 miles of aqueducts to a series of local reservoirs. Reservoirs nearest LBNL are Shasta Reservoir with a capacity of over two million gallons serviced by a 12-inch pipe and Berkeley View Reservoir with a capacity of over three million gallons serviced by a 6-inch pipe.. To supplement the water supply provided by EBMUD, LBNL operates and maintains three 200,000-gallon water storage tanks on-site for emergency water supply in the event of service interruption from EBMUD. During 2003, water consumption for the entire Laboratory was about 41.6 million gallons. Personal use accounted for 20.5 million gallons with process use (e.g., research, landscaping) accounting for the remainder. This total represents a 47% reduction from the 78.6 million gallons used in 1990.

LBNL's sanitary sewer system connects to the City of Berkeley system, which, in turn, terminates at the EBMUD wastewater treatment plant in Oakland near the eastern entrance to the Bay Bridge. Annual wastewater generation at LBNL is approximately 38 million gallons, with personal wastewater and process water each accounting for approximately 50% of the discharge.

The EBMUD treatment plant serves 640,000 customers and is designed to perform primary and secondary treatment of wastewater prior to releasing water to the San Francisco Bay.

The LBNL storm drain system discharges into the North and South Forks of Strawberry Creek, which are part of the Strawberry Creek Watershed. The two forks join near the western edge of the University of California Berkeley campus. At that point, Strawberry Creek then flows westward through the City of Berkeley before it reaches San Francisco Bay. The creek travels underground in the City's storm drainage piping for much of the route from campus to the Bay. Creek flow data is not measured.

PG&E provides electricity and natural gas to LBNL. PG&E serves about 15 million people in a 70,000 square mile area of northern and central California. Electricity is delivered to the Laboratory's Grizzly Substation via two 115 kilovolt transmission lines, where it is then routed through the LBNL electrical distribution network to each building. LBNL also has a number of emergency generators set to start automatically after a power failure and provide power for critical services. Total capacity of these generators is over six megawatts. Total electrical power consumption at LBNL in 2003 was 74,500 megawatt hours.

Natural gas is delivered to the Laboratory through a 6-inch PG&E line that terminates at a meter vault near the western boundary of the site. A 6-inch gas line distributes high pressure natural gas throughout the site, except for two buildings. Given their location below the UC Botanical Garden, Buildings 73 and 73A receive their gas supply directly from a separate PG&E supply line. The internal distribution system includes pipes, valves, fittings, pressure-reducing stations, earthquake emergency shut-off valves, meters, and appurtenances. Natural gas usage in 2003 was approximately 1.6 million Therms.

At the ALS, electrical power at 480 V is distributed to switchboards inside the new addition and then to 480-V process loads and 277-V area-lighting loads. Local step-down transformers are used for loads requiring lower voltage. Cranes, heating and ventilating equipment, pumps, and miscellaneous motor loads are supplied by motor control centers. High-pressure metal-halide lighting has been provided and enhanced by task lighting where appropriate. A 300-kVA emergency generator has been installed to provide emergency power to critical ALS systems. Communication is provided by a telephone system, a closed-circuit intercom in the tunnels that house the accelerators, and a local building-paging system.

Utilities provided within the facility include low-conductivity water, compressed air, dry nitrogen, natural gas, industrial cold water, a sanitary sewer, and high-pressure fire-protection water mains. The linac, booster, and storage-ring tunnels are provided with low-conductivity water and dry nitrogen. Access to the tunnels is provided by utility trenches located at intervals around each ring.

3.3.3 Ventilation and Thermal Stability Systems

The heating and ventilating system is designed to maintain a uniform 75° F temperature in the entire building and to provide forced-air circulation during the summer. Certain areas will be temperature-controlled to ±1° C as explained in the next paragraph. Exhaust fans will be used to ventilate the tunnel areas.

Guiding the high-brightness radiation generated by the ALS through monochromators and onto samples located tens of meters from the storage ring requires exceptional stability on the part of storage-ring structures, the stored electron beam, and the experimental equipment. A major study of stability issues has showed that a 1° C temperature change perturbs the position of the electron beam in the storage ring by 1 standard deviation (σ), but stability to 0.1 σ is needed. A layered stability-control strategy was adopted that consists of kinematic mounting for mechanical stability, temperature control of the storage ring, beamlines, and experimental areas to ±1° C to bring motion within range of the electronic feedback system that controls the electron orbit.

To achieve temperature control of the storage ring and the experimental areas, a new chilled-water plant and air-conditioning system was added to the scope of the ALS project [Keller, 1990]. The chiller plant supplies chilled water necessary for air conditioning. A separate, two-story, reinforced concrete building of about 6,300 square feet (35 feet by 92 feet) has been constructed south of the ALS. The chiller plant consists of 6-MW cooling tower, chiller units, pumps, electrical equipment, and associated piping. The building provides space for an additional cooling tower and chillers.

Thermal stability in the storage-ring enclosure is accomplished through the use of chilled-water fan-coil units on the walls of the storage ring, which provide cooled air to the storage ring. Thermal stability in the experimental areas is accomplished by means of chilled-water cooling coils in the ALS roof-top air-conditioning units, which provide cooled air to the building ducted-air-distribution system. Terminal reheat coils provide final control. Each fan-coil unit, roof-top unit, and reheat-coil has a temperature sensor with associated valves and controls to maintain final building temperature within 0.5 °F.

3.3.4 Accelerator Systems

As a third-generation synchrotron source, the ALS is based on the use of an electron storage ring specifically designed to have a very low emittance and several long straight sections containing insertion devices (wigglers and undulators). The combination of a very low emittance storage ring with optimized undulators makes possible the generation of radiation with a spectral brightness that is increased by a factor of 20 or more (depending on the spectral region) over that of existing, second-generation sources. Table 3-1 lists the main parameters of the ALS Storage Ring:

Table 3-1. Main Parameters of the ALS Storage Ring

Beam energy [GeV]	
Nominal	1.9
Minimum	1.0
Maximum	1.9
Circumference [m]	196.8
Beam current [mA]	
Multibunch	400
Single bunch	65
Berm emittance, rms [nmárad]	
Horizontal	< 10
Vertical	< 1
Relative rms momentum spread	
Multibunch	8.0×10^{-4}
Single bunch	13.0×10^{-4}
Nominal bunch duration, FWHM [ps]	30-50
Radiation loss per turn [keV]	92
Length available for insertion devices [m]	4.5

The ALS accelerator complex consists of a 50-MeV electron linear accelerator, a 1.9-GeV, 1-Hz booster synchrotron, and an electron storage ring optimized to operate at 1.9 GeV. The linac and booster are located inside the storage ring to avoid interference with user beamlines and to make best use of the layout of the original building.

The ALS linac is a conventional constant-impedance structure operating at 3 GHz (S-band) with two accelerating sections. The linac is fed by a 120-kV electron gun and bunching system that forms single S-band electron bunches with a charge of greater than 2 nC per bunch. All components of this system are housed in a concrete enclosure in the center part of the ALS building.

The linac injects electrons into a 1.9-GeV, 1-Hz booster synchrotron, from which they are extracted after acceleration for transfer into the storage ring. The booster has a 75-meter circumference and a missing-magnet FODO lattice with four-fold symmetry. In normal operating mode, the 1-Hz repetition rate permits filling of the storage ring to its nominal operating current of 400 mA in less than fifteen (15) minutes. In this mode, the beam lifetime is dependent primarily upon Touschek scattering and fills typically need to be performed every 8 hours. In Top-Off mode, the beam current is maintained at a nominal 500 mA and smaller injections are performed at a much higher frequency. Like the linac, the booster has been installed in a concrete tunnel in the area of the ALS building under the dome.

The storage ring is designed as a third-generation synchrotron-radiation source with a small natural emittance and long, dispersion-free, straight sections for insertion devices. Performance characteristics of the ALS are determined primarily by the design of the storage ring magnet lattice—the arrangement of bend and focusing magnets in the ring. The ALS lattice is optimized for the use of insertion devices. The magnet lattice contains 9 identical segments (superperiods), each of which is an achromatic arc comprising three combination gradient-bend magnets except when replaced by super-bends, six quadrupole focusing magnets, and four sextupole magnets in the triple-bend achromat arrangement (TBA). The storage ring has a design horizontal emittance of 3.5 nm-rad when operating at 1.9 GeV. Although the original storage ring operating energy is 1.5 GeV, the ring is capable of operating over the range from 1 to 1.9 GeV.

On its way around the storage ring, the electron beam travels through 12 monolithic, machined-aluminum vacuum chambers (one for each arc), which will maintain the base pressure in the storage ring to about 0.1 to 1 nTorr, and 12 straight sections connecting the arcs. Of the 12 straight sections, one is occupied by injection hardware and one by two 500-MHz rf cavities, leaving 10 straight sections available for undulators and wigglers up to 4.5 m in length. Each arc of the storage ring is fitted with four bend-magnet ports that can be used to access bend-magnet radiation. Of the maximum of 48 ports, 24 are so-called prime ports with smaller vertical beam sizes that will be developed first.

The ALS produces electron beams that are bunched rather than continuous. The storage-ring rf system has a frequency of 500 MHz, so the spatial separation between bunches is 0.6 m and the temporal separation is 2 ns. The storage-ring lattice, the rf system, and the impedance of the vacuum-chamber hardware determine the length (spatial and temporal) of the bunches. For the ALS at the nominal current of 400 mA, the predicted full-width-at-half-maximum (FWHM) value of the bunch length is 35 ps. To avoid trapping positive ions in the potential well of the negatively charged electron beam, the multibunch mode with a 400-mA current will have 276 consecutive bunches, followed by a gap of 52 empty buckets. For particular experiments—for example, those involving time-of-flight measurements—it can be advantageous to have only one or a few circulating electron bunches in the storage ring. In the few-bunch mode, the nominal current per bunch will be 32 mA and the bunch length (FWHM) is predicted to be 55 ps, although still larger bunch currents may be tolerated. For a single pulse, the repetition rate would be the circulation time of the beam, 656 ns.

Multibunch Mode

In the multibunch mode, the electron gun (operating at 120 kV) produces a string of pulses, each about 2 ns long, separated by 8 ns (corresponding to 125 MHz). The number of pulses in this string can be varied between 1 and 12, giving a "macro-pulse" length of 2 to 100 ns. Before entering the linac, the pulses are compressed from 2 ns to 0.2 ns by the action of two sub-harmonic bunchers, operating at 125 MHz and 500 MHz. This operation ensures efficient capture of electrons in the linac. The 50-MeV beam is then transferred into the booster synchrotron by single turn, on-axis injection by means of a full-aperture kicker magnet. After acceleration to 1.9 GeV, the electron beam is extracted, again in a single turn, and transferred to the storage ring, where it is captured in a 500-MHz accelerating structure. This highly efficient acceleration/capture process is repeated until the required current is accumulated in the storage ring. Six hundred (600) cycles (at a rate of 1 Hz) are required to reach 400 mA of stored current.

Few-Bunch Mode

In the single- or few-bunch mode, the electron gun produces a single pulse, rather than multiple pulses. The transfer and acceleration processes are then identical to those used in the multibunch mode. The timing system for the accelerators is designed such that the single pulse can be placed at any point around the circumference of the storage ring. In this situation the current accelerated in the booster will be about one- third that in the multibunch mode, and filling times are about 0.1mA per cycle per bunch. Therefore, about 320 cycles (at a rate of 1 Hz) are required to fill each bunch to 32 mA.

After filling, the injection system is turned off and the stored beam is allowed to decay naturally. After the decay process has reached the level where the beam must be replenished refilling takes place as described above. The design value of the beam 1/e-lifetime is about 10 hours. Refilling is normally done at 8-hour intervals.

The storage ring is normally operated 24 hours per day (three 8-hour shifts) five to seven days per week.

Top-Off Mode

In Top-Off mode, the nominal current of 500 mA is maintained to within a few percent. Upon confirmation that the storage ring and beamlines are in the appropriate mode, Top-off injections may be performed. These consist of few bunch injections totaling ~1 nC. The timing system described above is used to place these bunches adjacent to the stored electron bunches which are to be ‘topped off’. After passing through the septum magnet, the two sets of bunches merge and the total charge for those bunches is restored to the nominal value. This process is then repeated until all bunches are topped off.

Beam Test Facility and Booster-To-Storage Ring Beamline

The Beam Test Facility (BTF) makes use of the ALS linac and the Booster-To-Storage ring (BTS) beamline makes use of the ALS booster. Between storage-ring filling operations, the 50-MeV linac electron beam can be transported via a transport line through the wall of the linac cave into an experimental vault adjacent to the linac cave [Leemans *et al.* 1993]. The maximum energy and current of the linac for BTF operation are identical to those of the linac for storage-ring injection. Between storage-ring filling operations the 1.5-GeV booster electron beam can be transported via a short transport line to an adjacent beamline within the booster shielding. The maximum energy and current of the booster for BTS operation are identical to those of the booster for storage-ring injection.

3.3.5 Insertion Devices

There are 10 storage-ring straight sections available for insertion devices (undulators and wigglers). The magnetic structure of an insertion device consists of an array of alternating polarity dipoles. A planar insertion device has vertically oriented poles of alternating north-south polarity which causes relativistic electrons of energy E to undergo a periodic electron trajectory of period λ_u in the horizontal plane. The resultant synchrotron radiation is linearly polarized in the horizontal plane. An elliptically polarizing undulator (EPU) has a magnetic structure with vertically and horizontally oriented periodic magnetic field arrays. The two field components are 90° out of phase, and the relative strength can be varied to control the ellipticity of the orbit and polarization of the radiated spectrum. A helical electron trajectory and circularly polarized light are produced when both components are of equal strength.

Undulators can provide radiation of unparalleled spectral brightness, with a significant degree of spatial coherence. The spectrum of undulator radiation consists of a series of narrow peaks at a fundamental photon energy and its harmonics. By varying the undulator magnetic field, which decreases as the gap between the poles of the undulator increases, the photon energy of the fundamental and the harmonics can be scanned. At the ALS, the third and fifth harmonics of the radiation spectrum are used to extend their spectral range to higher photon energies (2.5 keV) than can be reached with the fundamental alone (0.55 keV).

Radiation from a wiggler or the superconducting dipoles (superbends) are used to provide higher energy photons than are obtainable from an undulator. A wiggler produces a broadly peaked (or "white") spectrum of X-rays, which is spread into a relatively wide fan of radiation emerging from the insertion device. A wiggler has a critical photon energy ε_c , defined as the photon energy above which half the total power is radiated. At the high-energy end of the broad wiggler spectrum, the flux drops rapidly but is still one-tenth of its maximum value at photon energies near $4\varepsilon_C$, so the W11 wiggler, with a peak field of 1.85T, provides photon energies into the hard X-ray region above 10 keV, although the increased spectral range comes at the expense of reduced brightness, as compared to that of undulator radiation.

Table 3-2 provides a summary of insertion devices installed at the ALS. The U5, U8, U10, and W11 devices occupy full straight sections. The EPUs and IVID (in-vacuum insertion device) are designed to occupy half-straights. Two EPUs are installed in the sector 11 straight. A chicane magnet at the center of the straight deflects the trajectory to provide an angular separation in the fans emitted by the two devices, thus providing two sources for two independent beamlines.

Chicane magnets are also installed in the sector 4 and 6 straights to accommodate future installation of a second insertion device in each straight.

Table 3-2. Insertion Device Parameters for Devices Installed by the End of FY05.

Device	Beamline	Energy Range (at 1.9 GeV) [eV]	Period Length [cm]	No. of Periods	Operating Gap Range [cm]	Peak Effective Field Range [T]
U5	8.0	80–3000	5.0	89	1.4–4.5	0.85-0.10
U5	7.0	80–3000	5.0	89	1.4–4.5	0.85–0.10
U8	12.0	20–1900	8.0	55	2.5–8.3	0.80–0.7
U10	9.0	8–1500	10.0	43	2.4–11.6	0.98–0.5
U10	10.0	12–1500	10.0	43	2.4–11.6	0.80–0.5
EPU5	4.0.1	80–3000	5.0	37	1.40–5.5	0.85–0.10 (vertical field) 0.57–0.10 (horizontal field)
EPU5	11.0.1	75–3000	5.0	37	1.38–5.5	0.86–0.10 (vertical field) 0.58–0.10 (horizontal field)
EPU5	11.0.2	75–3000	5.0	37	1.38–5.5	0.86–0.10 (vertical field) 0.58–0.10 (horizontal field)
W11	5.0	4000-18000	11.4	29	1.4	1.85
IVID	6.0.1	120-5000	3.0	48	0.55-2.3	1.5-0.2

The major subsystems of the insertion devices are (i) the magnetic structure, which consist of magnetic assemblies attached to backing beams; (ii) the support and drive system, which includes the supporting framework for the magnetic structure, the gap adjustment system, and in the case of EPUs, the mechanism for longitudinal motion of magnetic structure quadrants; and (iii) the vacuum system, which includes a vacuum chamber and its associated pumping system. Figure 3-5 shows an example insertion device currently in operation.

Figure 3-5. EPU5 prior to installation.

3.3.6 Beamline Systems

Beamline systems in this context means the radiation source, front end, and beamline photon transport system. Radiation source and front ends are designed by ALS staff. Beamlines are generally designed by ALS staff, but in a few cases have been designed by user groups. In order to have uniformity of approach and a thorough analysis of functionality and safety of these complex systems, we have developed a formal set of checks and reviews at all stages of the design, installation and testing process. The review process is organized under the direction of the Beamline Review Committee, a formally chartered group. The basic stages are:

- Conceptual Design Review (CDR); this assesses issues of overall concept, space, general safety issues (for example sample containment, access in case of emergency etc.).
- Beamline Design Review (BDR); this evaluates the beamline design in detail, including mechanical safety issues such as seismic restraint, equipment protection, and radiation protection and safety systems. On passing this review, the beamline builders can proceed to procurement and construction.
- Beamline Readiness Review (BRR); this review checks to see that the plans as described in the BDR have been correctly executed. Plans of the completed system are presented and checked against the documentation provided at the BDR and against the general criteria for an operational beamline as described in Pub 3114.
- Beamline Readiness Review Walkthrough (BRRW); this checks the plans as described at the BRR against the physical hardware on the floor, and involves keying on the beamline and equipment and radiation protection and survey checks. Samples of checklists for key enable and radiation survey are contained in Pub 3114.

These four stages of review are supplemented by engineering reviews of all major subsystems during the course of the construction project.

Subsequent to authorization for operation, the critical systems are under formal configuration control and are subjected to routine testing and verification. These functions are governed in a detailed set of procedures that are administered through the ALS Procedures Center. The procedures themselves describe all of the critical processes for safe operation and protection and maintenance of equipment at ALS. The full list of these procedures is at http://alsintra.lbl.gov/procedures/procedures.htm, this link is also provided in Appendix 1, Operational Procedures.

3.3.6.1 Radiation Sources

The ALS has over 40 beamlines (2005), and these cover from the mid infrared region (few meV energy) to the hard X-ray (50 keV). Figure 3-6 shows the range of beamlines that we have in 2005. This large range of energies is provided by several different types of radiation sources; normal bend magnets (1.27T), superconducting bend magnets (5T), a wiggler (1.94T, 11.4 cm, 52 poles), and undulators of periods 5, 8 and 10 cm. The original suite of undulators were full length devices (around 4.5 m long) occupying the whole straight section (in straights 7, 8, 9, 10, 12). Later undulators have occupied chicaned straights (4 and 11) where 2 undulators are inclined with respect to each other and occupy a straight length of around 2m (Figure 3-7). These are all 5 cm period elliptically polarizing undulators. In general, the power, flux and brightness radiated by these devices ranges from the normal bending magnet at 15W/mrad, 10^{13} ph/sec 0.1% band 1 mrad and 10^{16} ph/sec 0.1% band mm^2 $mrad^2$ to a high field undulator at 5 KW (total), 10^{15} ph/sec 0.1% band (central cone) and 10^{19} ph/sec 0.1% band mm^2 $mrad^2$ respectively.

3.3.6.2 Front Ends

Front end design differs in detail on all the above radiation sources but there are many common features that are necessary to all systems. Here we describe the chicaned undulator straight, which is the most complex front end. Such a system is shown in Figure 3-8. The function of the front end is to define the beam within designed angular ranges, to protect the storage ring in case of a vacuum problem on the beamline, and to provide a means of shutting off the storage ring from the beamline for purposes of radiation protection during injection. In Figure 3-9, beam first passes a vacuum valve that can be used for isolating the vacuum of the storage ring from the front end section. The beam is then defined in angular aperture by horizontal and vertical beam defining apertures. These are high power components and are made of a high strength copper alloy and are internally cooled. The front end shown is particularly complex as it accommodates two beams, angularly split in the horizontal direction, from 2 undulators in a chicaned straight section. The two beams are isolated in terms of radiation from the beamline by two personnel safety shutters (PSS). The shutters contain water-cooled absorbers to absorb the beam power, as well as thick blocks of tungsten to absorb high-energy gas bremsstrahlung radiation formed by collision of electrons in the storage ring with residual gas molecules. Downstream of the PSSs we have a fast valve that closes in a few msec, when triggered by an upstream sensor in the beamline. The sensor triggers when it sees a sudden rise in gas pressure. This mechanism allows time for the valve to close, before any gas from a venting problem hits the front end. Beam then passes through a regular vacuum isolation valve and onto a mirror chamber. Unlike many storage ring facilities, ALS has many of the first optics inside the storage ring shielding. This has many optical advantages and gives more flexibility in terms of beamline design. In a chicaned undulator straight, this mirror tank contains two mirrors, shown in Figure 3-7. The mirrors face each other, so that the two beams cross downstream. These mirrors have to be remotely operated and typically have pitch, yaw and roll controls.

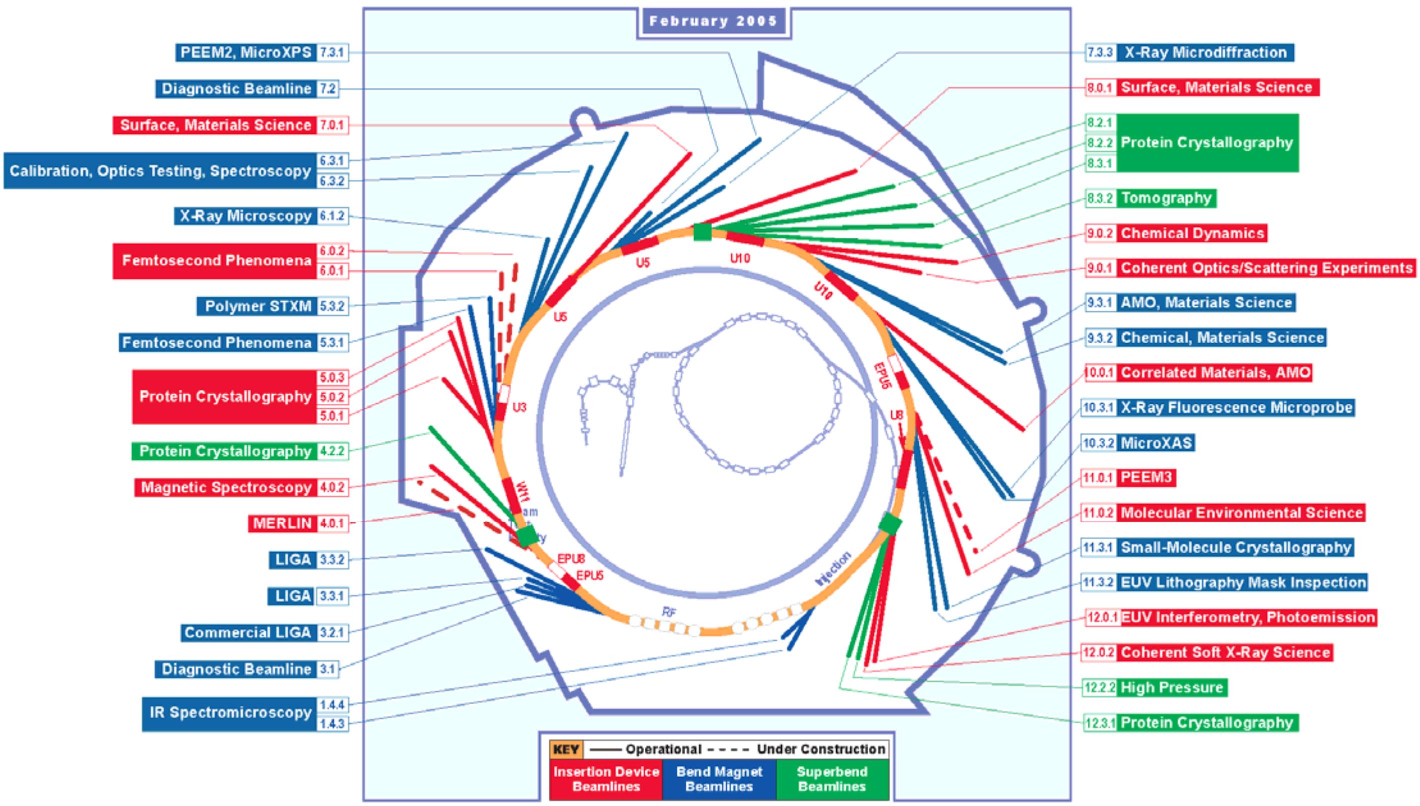

Figure 3-6. Beamlines at the ALS in 2005

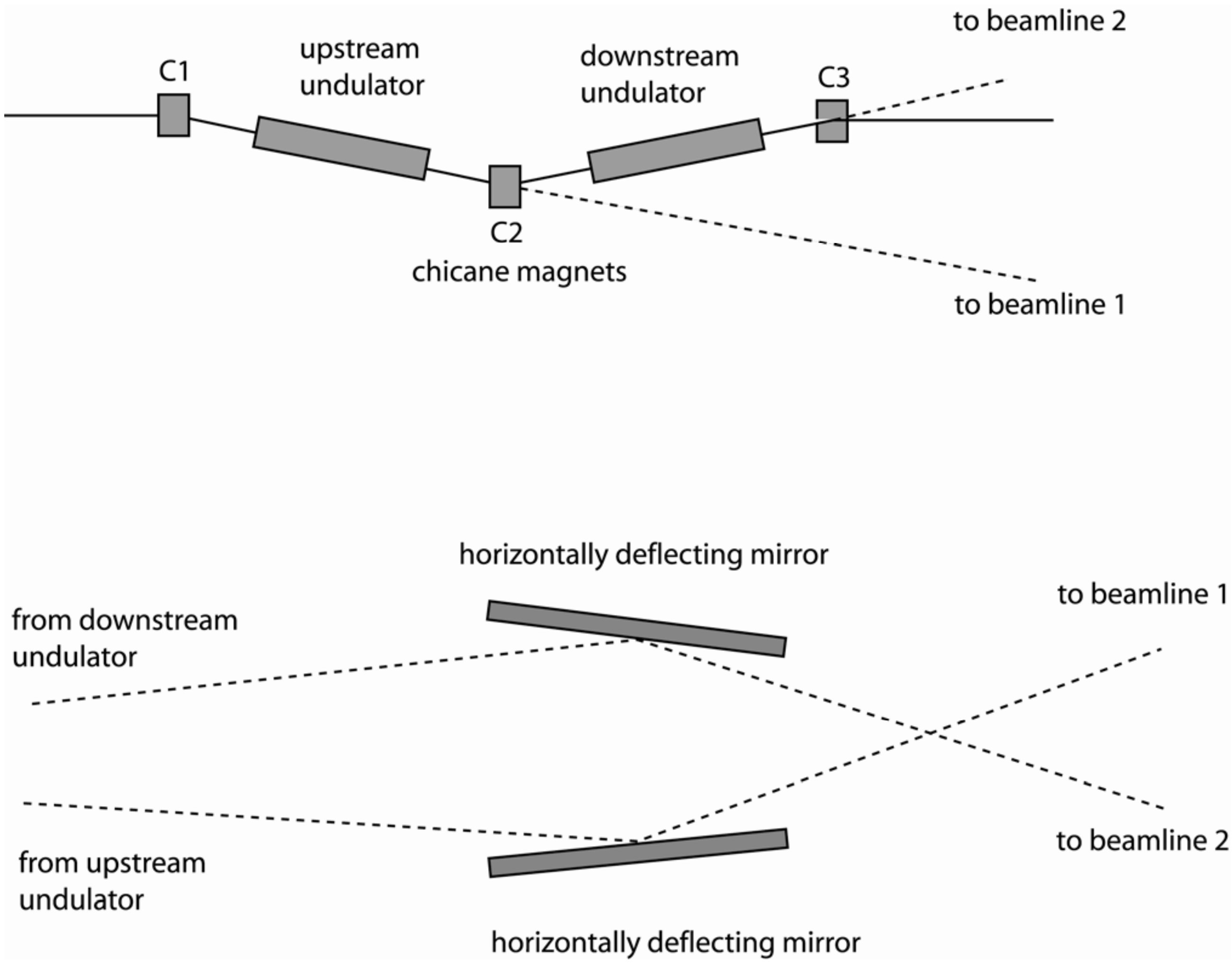

Figure 3-7. Arrangement of a chicaned straight with beamline mirrors

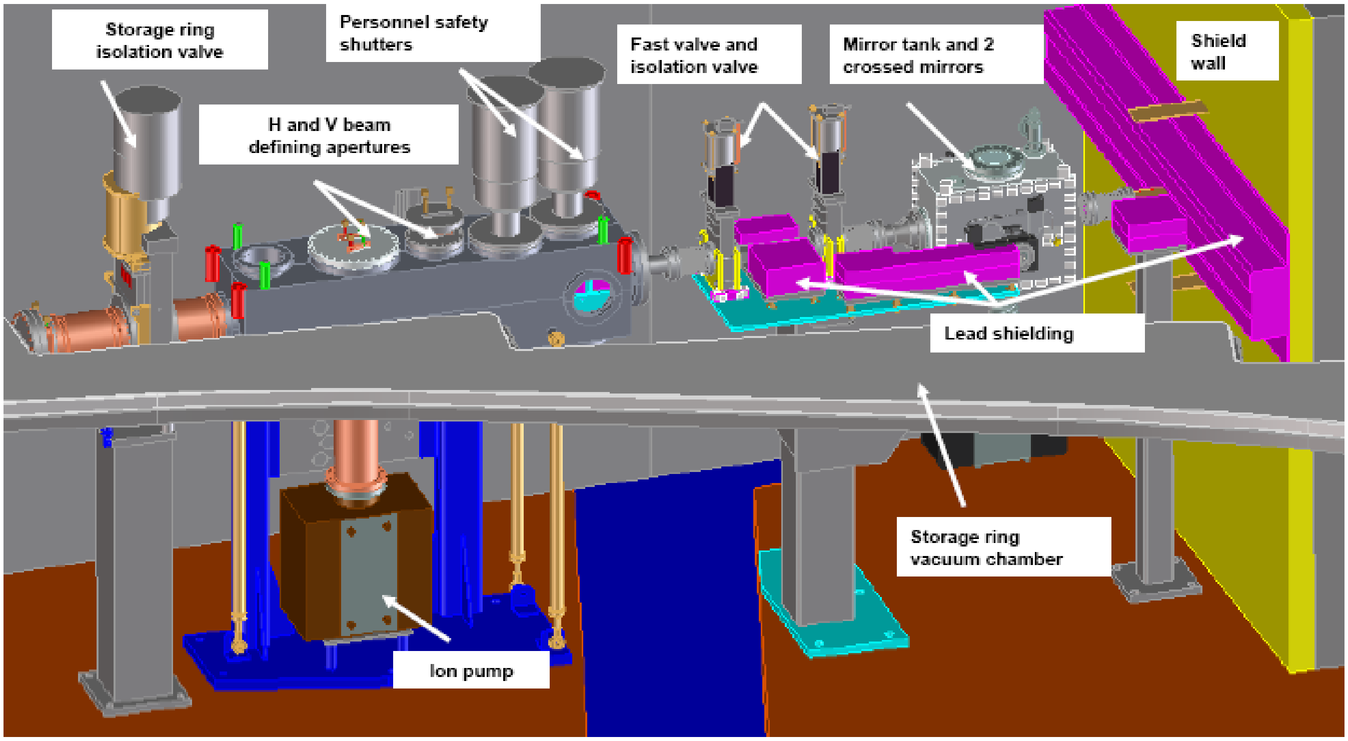

Figure 3-8. Front end section from a chicanes straight section

Again, due to the very high power densities, the mirrors are heavily water-cooled. The area around the mirror tank from just upstream to the shield wall has heavy additional lead shielding to ensure that gas bremsstrahlung cannot escape through oblique angles through the shield wall. The opening and closing of valves and shutters in the front end, together with monitoring vacuum pressure and water flow is done by a front end Equipment Protection System (EPS) that is operable from the beamline. The opening of the PSSs is done by the Radiation Safety System (RSS). The RSS has several functions. It interfaces to the storage ring control system, and in the presence of a beamline radiation fault condition, the RSS will trip off the storage ring RF system. It also allows the beamline to be disabled, by removal of a key from the beamline control racks in the experimental area. This would be done during shutdowns, and other periods when modifications were being made to beamline apparatus. In hard X-ray beamlines the end station at the end of the beamline is enclosed in a radiation hard hutch. The hutches come in two varieties, a large walk-in hutch and a mini-hutch with a sliding door. Both types have a radiation safety system that monitors the state of the hutch and the personnel safety shutter. In the presence of a fault that indicates that the hutch is open and the PSS is open, the RSS will trip off the storage ring RF system. The last component in the front end is the shield wall. This is constructed from high density concrete and is up to 1 m thick. This shielding is supplemented by additional lead shielding at beam height on the inside of the shield wall (upstream) as well as polyethylene and lead inside the wall penetration for neutron absorption. A key part of the design procedure for beamlines and front ends is to ensure that all synchrotron radiation, direct and scattered, and gas bremsstrahlung from the storage ring is contained and collimated within tight position and angular constraints. Radiation that comes out of the shield wall is then contained within the beampipe, within an exclusion zone where access is not allowed, or dumped into a backstop or collimator downstream. All shielding is designed by a process of raytracing from all possible radiation source points.

3.3.6.3 Beamlines

Beamlines come in two fundamentally different types, windowless VUV soft X-ray beamlines and windowed hard X-ray beamlines. They are fundamentally different because of the hazards involved in each case and the safety systems we have to employ and so are described here separately.

a) VUV soft X-ray beamlines

The layout of one of the latest generation of soft X-ray beamlines is shown in Figure 3-9. As shown in Figure 3-7, this is one beamline from a chicaned straight, so there is beamline similar in design to this as a mirror image, branching towards the top of the page from the front end (from a second M1 mirror as shown in Figure 3-8). In this case, the M1 mirror is a sagittal cylinder, providing focusing to the entrance slit of a downstream monochromator. The monochromator itself is a converging beam variable line spacing plane grating monochromator, with the converging beam being provided by a spherical M2 mirror. This disperses the radiation, and focuses single wavelengths to a plane of dispersion at the exit slit of the monochromator. The photon energy is changed by simple grating rotation. The entrance slit, M2 mirror and grating are all heavily cooled. Light that has been diverging in the horizontal plane from the undulator is collected by an elliptical M3 mirror and focused close to the exit slit. Light is then further demagnified by a second elliptical mirror M4 onto the sample. In the vertical direction, another elliptical mirror refocuses the light from the exit slit and demagnified it to the sample. Most of these mirrors and grating are controlled by motors and encoders, from the beamline control system. The beamlines typically are 30 – 35 m in length from the radiation source. The physical arrangement of the system is shown in Figure 3-

10 (for sector 11.0), and shows the front end, shield wall, and the two beamlines almost side by side, but in reality branching away from each other by around 12 degrees. The left hand beamline feeds the PEEM3 end station (a photoelectron microscope), and the right hand beamline feeds the Molecular Environmental Science (MES) end stations. The PEEM3 line has one end station. The MES beamline splits into several branchlines, feeding individual end stations. The adjacent beamlines 11.3 (upper) and 10.3.2 (lower) are not shown for clarity. The safety exit (yellow stairs) from the storage ring roof, to the periphery of the ALS is shown (yellow lines). The vacuum pressure in the beamline is monitored by ion gauges and other types of low vacuum gauges, and sections are isolated by vacuum valves. Opening and closing of valves, monitoring of the vacuum pressures and monitoring of the status of water flow on cooled components are all controlled by the beamline Equipment Protection System (EPS). The Radiation Safety System (RSS) is simple in the case of all-vacuum beamlines as described here. The RSS has an enable key. The RSS checks that the redundant limit switches on the PSS are correctly enabled, and if the enable key is energized, gives a ‘ready’ signal. The EPS can then open the PSS if requested. The system usually has a fast valve sensor close to the experimental end station, which if activated, triggers a fast valve in the front end. This protects the storage ring from beamline vacuum accidents. Due to the very short absorption length of VUV and soft X-ray radiation in air, and to protect optics, these beamlines and endstations are always at high to ultrahigh vacuum. In the special case of soft X-ray microscopes, a very narrow beam of radiation is extracted through typically a 0.5 mm diameter 100 nm thick window into air or helium. The radiation is absorbed over a very short distance in air (~1 mm) and passive devices together with operational procedures give adequate radiation protection.

b) Hard X-ray beamlines

The layout of a typical X-ray beamline is shown in Figure 3-11. In general the front end layout is similar to that previously described for a chicaned undulator front end, but there would usually be a Beryllium window upstream of the mirrors, and in the case of the wiggler beamline in straight 5, there is a carbon filter just upstream of this window to absorb low energy light. The system drawn here in Figure 3-11 and 3-12 is specifically for the superbend protein crystallography beamlines, and is typical of the latest designs used. Light is vertically collimated by an M1 mirror inside the shield wall reflecting and focusing in the vertical direction. This mirror has remote pitch and bend controls. The beam then passes through the shield wall and onto the monochromator. This is usually a commercial system consisting of a pair of crystals (Si [111]) that define the photon energy. The energy is changed by rotation of the crystals and translation of the second crystal. Beam then passes to a vertical reflecting toroidal mirror that focuses from infinity in the vertical direction and from the real source in the horizontal direction. The beam is focused into the end station X-ray hutch where experiments are conducted. The general arrangement of such a beamline is shown in Figure 3-12, which shows 3 beamlines in one superbend sector (8.2 and 8.3). The beam emerging from the shield wall first passes through two bremsstrahlung collimators. The beam pipe is stainless steep wrapped in lead with a stainless steel tube outer covering. Beam then enters the monochromator (large circular blue structures), which has internal shielding, and finally onto the M2 refocusing mirror chamber. Each of the 3 lines terminates in a mini-hutch. The upper hutch is shown with complete shielding and the two lower ones with shielding removed, revealing the end station goniometer and detector. X-ray end stations come in two varieties a) conventional large walk-in hutch and b) mini-hutch. The conventional hutches can be accessed using an interlocked Radiation Safety System (RSS). The shutter is requested closed, and when closed, the door may be unlocked via a pushbutton. When locking up the hutch, the hutch is first visually searched, then a search button inside the hutch is pressed, and the door closed and locked. After a minimum period of 15 seconds, during which alarms are activated inside the hutch, the RSS enables the radiation shutter to open, if all interlock chains are complete. A request from the Equipment Protection System (EPS) then opens the hutch radiation shutter. In the case of the mini-hutch, entry into the hutch is via a hatch window, and physical entry of the whole body into the hutch is not allowed in normal operation except by special lockout procedure. The hutch search button and warning period and alarm are therefore not necessary in this case and the door access key has been replaced with a push button for ease of operation. All other functions of the RSS are retained. The major difference between VUV / soft X-ray and hard X-ray beamlines is in the shielding requirements. These are described in detail in Appendix A of the Beamline Design Guide (http://www-als.lbl.gov/als/bdguide/BDG.pdf). Hard X-ray beamlines have several unique hazards:

(1) Particularly in the case of superbends, where the critical energy is high (12 keV), extremely high doses can result through multiply scattered events. Shielding for scatter as well as direct radiation has to be extremely thorough. This is done through extensive use of lead shielding along the beamline around the beam tubes, around beamline components such as beam shutters, and use of other materials (for example copper and tungsten) within vacuum enclosures (such as for monochromators).

(2) Hard X-ray beamlines usually have a vacuum isolating beryllium window in the front end. This means that we need to be especially careful when removing parts of the beamline during any type of maintenance. Although the EPS would close all the relevant valves and shutters if it sensed that part of the beamline was at atmospheric pressure, it is not part of the radiation safety system. A strict system of procedures is maintained for accessing the shielding and for re-installation and checking prior to approved operation. During these

periods the beamline RSS is keyed off. Re-enabling requires a series of procedures to be activated. In addition, area radiation monitoring and routine checking of all beamlines are provided. Another supplement is the use of padlocks on flanges that are likely to be accessed frequently. The procedures are accessed through the procedure center at http://alsintra.lbl.gov/procedures/procedures.htm.

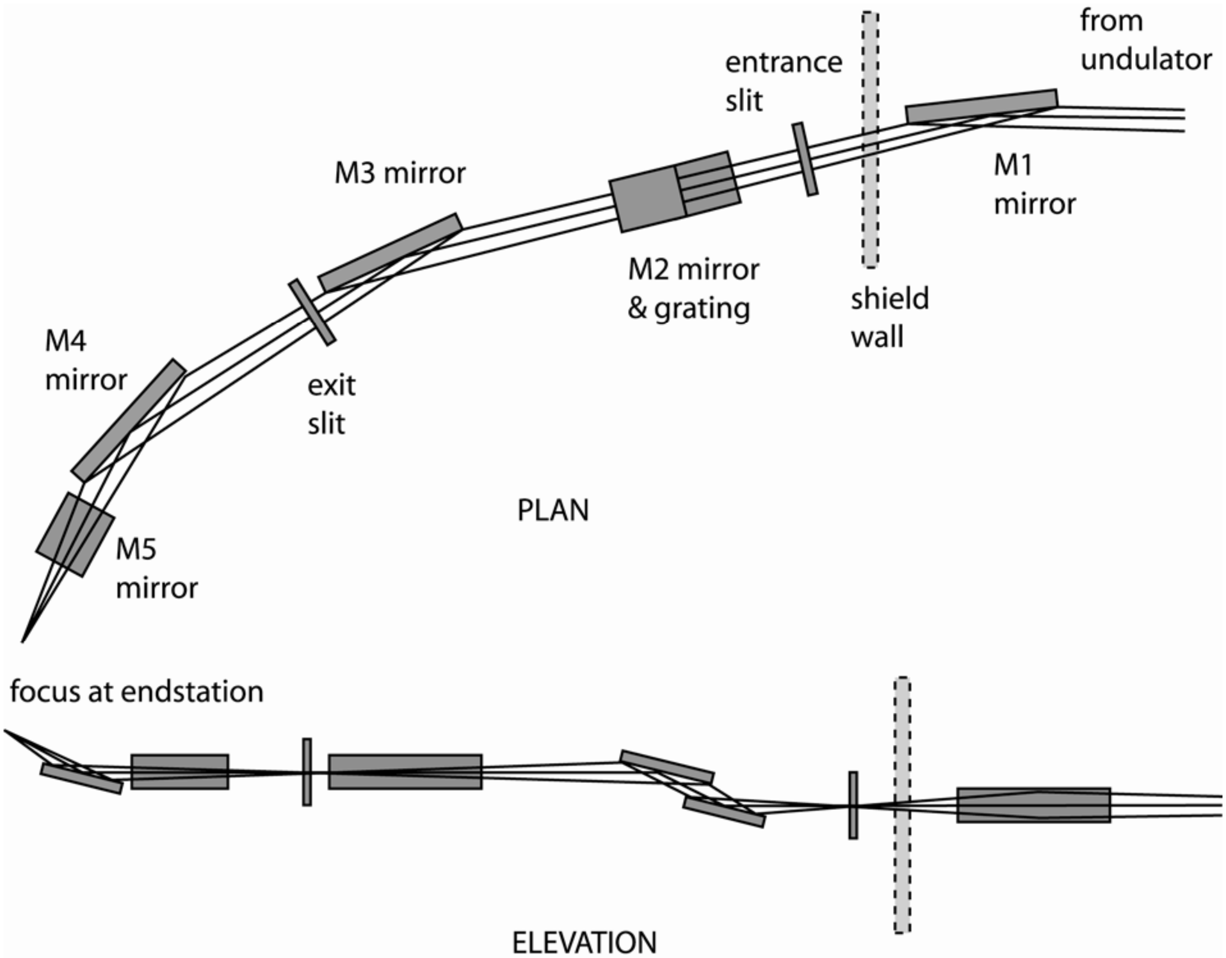

Figure 3-9. Optical layout of a soft X-ray undulator beamline: PEEM3, Sector 11.0

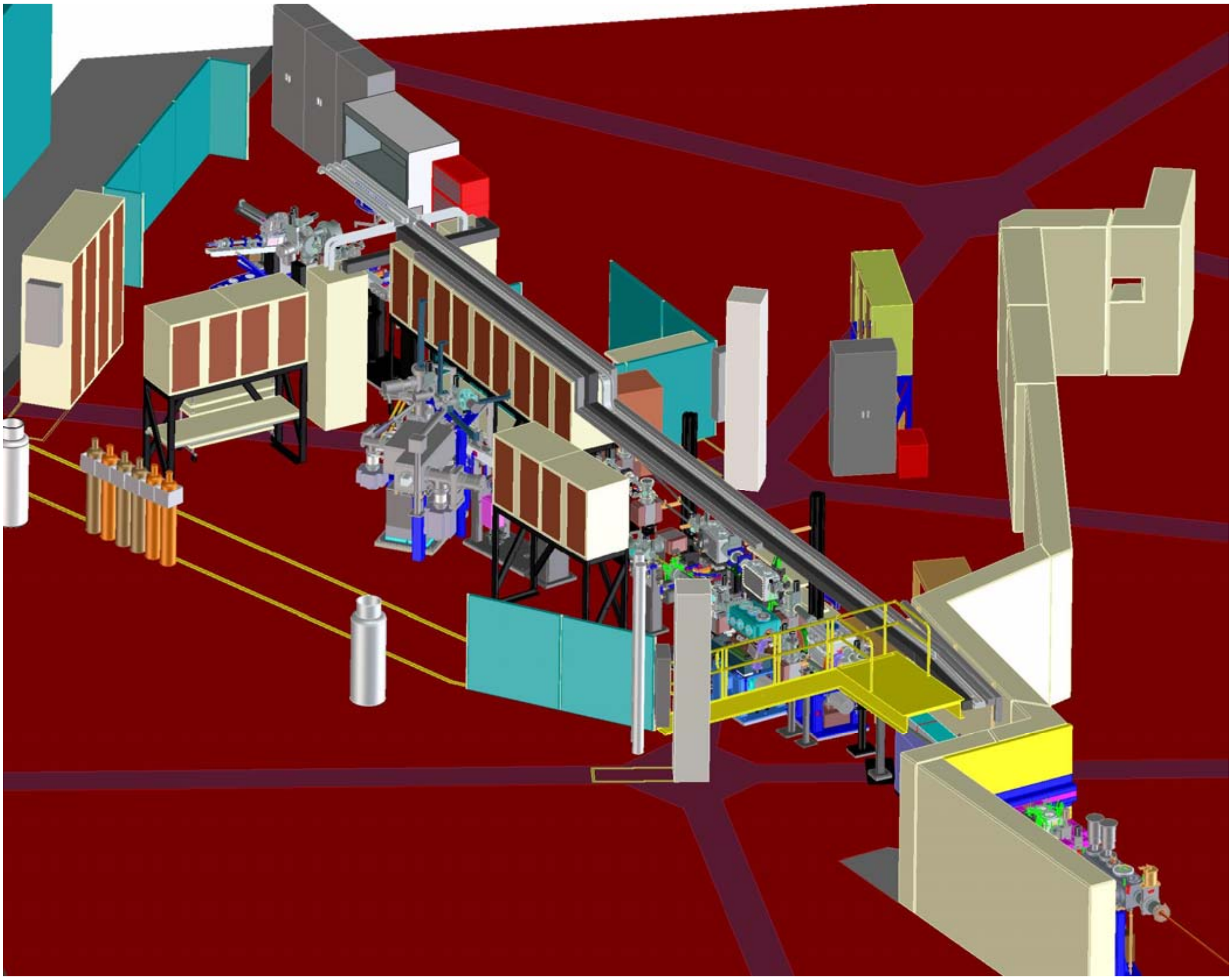

Figure 3-10. Schematic layout of a soft X-ray undulator beamline: PEEM3, Sector 11.0

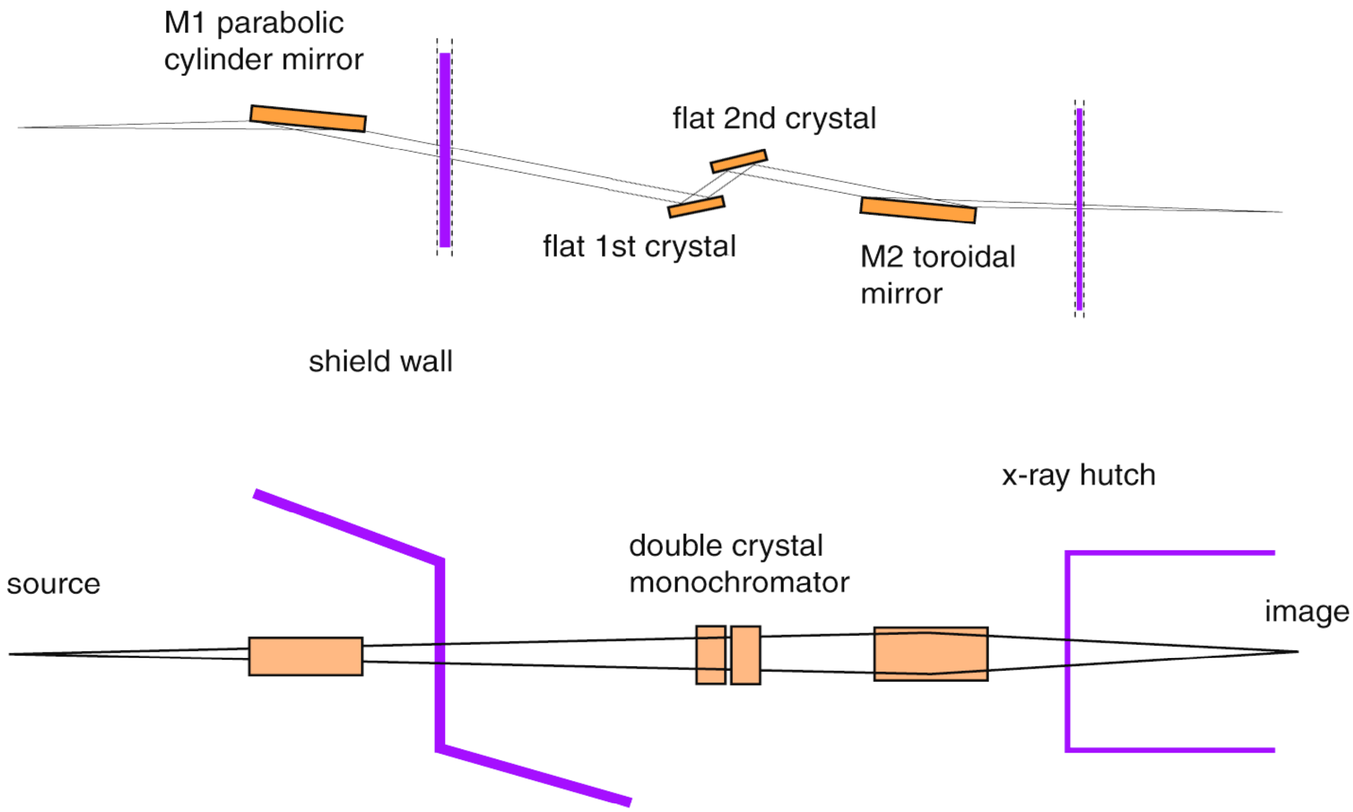

Figure 3-11. Optical layout of a hard X-ray beamline: Sector 8

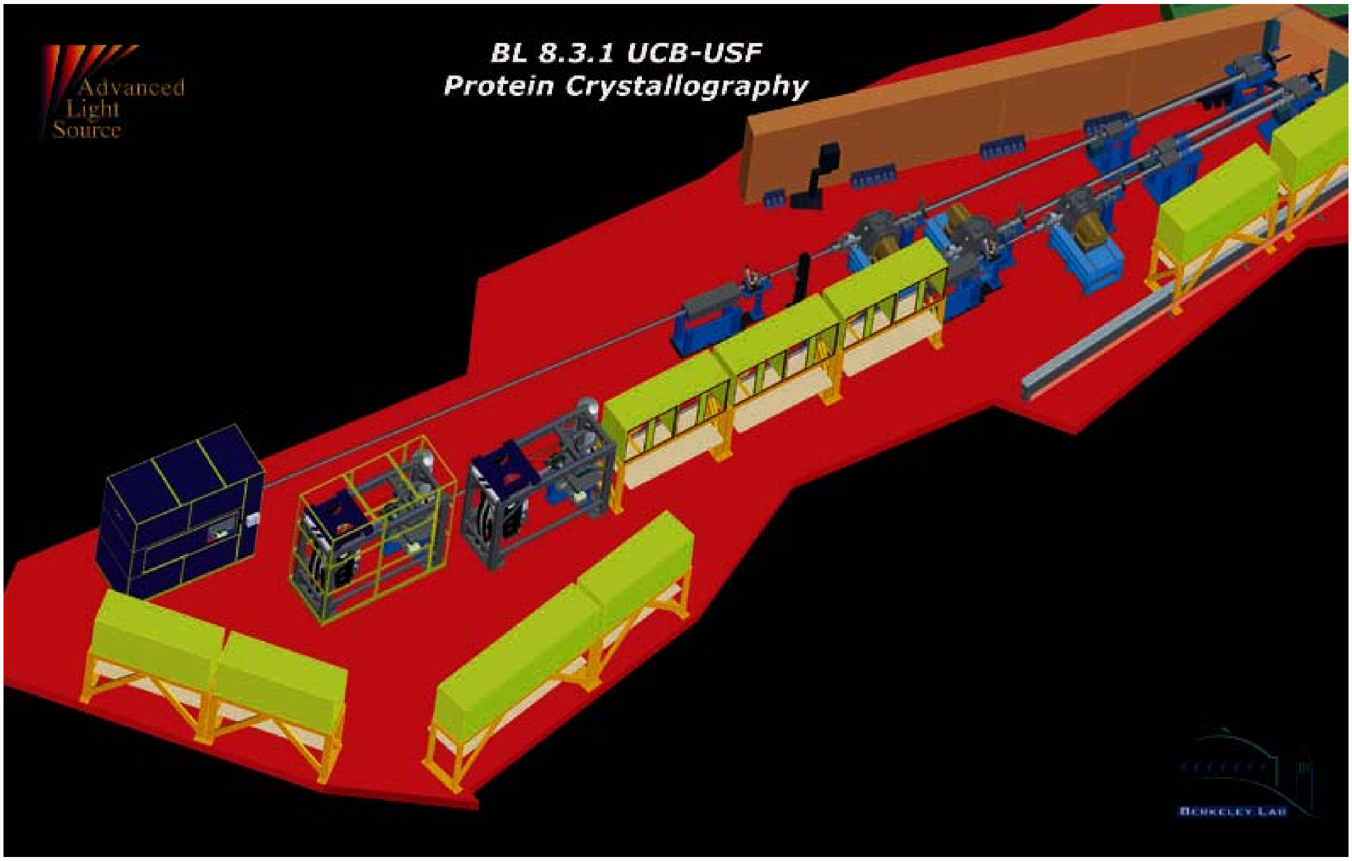

Figure 3-12. Schematic layout of a hard X-ray beamline: Sector 8.2, 8.3

3.3.7 Experiments

The beamlines guide the synchrotron radiation to the experimental areas. The beamline end station is responsible for providing the appropriate environment for experiment support and for investigator access. The end station may comprise a relatively complex set of components, such as a beam diagnostic region, plus a personnel safety shutter, and a fully shielded and interlocked hutch for experiments that use harder X-rays, or it may comprise simply an isolation valve and the experimenter's vacuum chamber.

The end station extends from the end-station interface through the experimental apparatus. Some branch lines may have several end stations in tandem and/or in parallel.

The end station instrumentation consists primarily of the experimental apparatus. It also contains minimal instrumentation to isolate the end station from the branchline. There are diagnostic components, which are used to align and qualify the upstream optical components. The instrumentation will vary depending upon the specific experiment requirements. Depending on the needs of the users, experimental areas may contain a number of manually or electrically operated vacuum isolation valves, vacuum delay lines, differential pumping stations (to permit samples to be at higher pressures than allowed in the beamlines), and radiation-transparent solid windows (to isolate the sample chamber from the beamline).

The equipment in the experimental areas will reflect the requirements and interests of both categories of users, members of PRTs and independent investigators who may use PRT experimental chambers or bring their own. Most will involve vacuum chambers with UHV capability, movable specimen stages for positioning and orientation of samples in the synchrotron-radiation beam, electron and photon detectors and spectrometers, and ancillary diagnostic instrumentation. Some areas will have cryogenic equipment. Some areas will be for the investigation of gaseous samples and will have mechanisms for introducing the sample into the chamber without degrading the UHV environment elsewhere in the beamline. Some areas may have the capability to fabricate specimens in-situ by, for example, molecular-beam epitaxy, or to subject them to structure- or behavior-changing treatments, such as changing the characteristics of a solution containing biological-cell structures. Some areas may have associated facilities nearby for sample preparation and hazardous material containment. All experimental areas will have extensive instrument-control and data-acquisition computer systems with links to the ALS computer system.

To a great degree, end stations for VUV and soft X-ray experiments with synchrotron radiation are based on a generic structure, namely, an ultrahigh-vacuum (UHV) chamber, to which numerous instruments for sample preparation, manipulation, and characterization, as well as detectors and spectrometers for electrons, photons, and ions, are appended, as required by the specific experiments to be conducted. For example, low-energy electron diffraction (LEED), reflection high-energy electron diffraction (RHEED), and scanning tunneling microscopy (STM) instruments are important for characterization of solid samples, whereas gas-phase samples require a gas-handling system in the experimental chamber, as well as a differential-pumping system to isolate the sample from the UHV environment of the beamline and the storage ring. For chemical reaction dynamics, end stations are somewhat more specialized. For example, lasers are used to create well-characterized initial conditions before the initiation of chemical reactions in chambers equipped with molecular beam sources.

For hard X-ray experiments, radiation-protection hutches are required for personnel protection, but maintenance of an ultra-high vacuum is not always needed in the sample chamber, a potential advantage for examining materials in near-natural environments. The absence of UHV vacuum chambers also makes it more practical to construct special-purpose experimental stations for specific purposes, such as a fluorescence X-ray microprobe.

3.3.8 Ancillary laboratory, shop and office space

Approximately 19,000 square feet of laboratory and office space has been constructed in the second floor or mezzanine of B6. 8,500 square feet of this is equipped with standard laboratory plumbing, ventilation, and other utilities. Much of this space is used for instrument, detector and laser development, and the rest is used for preparation of chemical and biological samples. The remainder of space in the mezzanine is used for office space.

The basement of B80 is primarily machine and electronics shop space, the main floor is primarily office space and the second floor houses both office and laboratory space.

3.4 RADIATION PROTECTION SYSTEM

3.4.1 Radiation Shielding

3.4.1.1 Shielding Policy

Goal

In order to ensure minimum risk to the general public and to facility personnel from operation of the ALS, it is LBNL policy to implement the Department of Energy regulatory radiation-safety limits, as currently expressed in 10 CFR 835. Accordingly, the radiation shielding design is based on the dual design goals of limiting the radiation exposure to the general public to less than 10 mrem/year (0.1 mSv/year) and limiting occupational exposure to laboratory workers to less than 250 mrem/2000-hour worker year (2.5 mSv/year) and to 1 rem/9000-hour worker year (10 mSv/year). The design goal for continuous occupancy is 0.5 mrem/hour (5 μSv/hour). These goals meet the DOE radiation-dose limit to the general public of 100 mrem/year and are far below the maximum allowable occupational dose limit of 5 rem/year.

Design

The ALS accelerator shielding configuration required to meet these design goals evolved, as described in the following sections. In brief, a basic concrete shielding design was developed. The design was based on conservative assumptions about accelerator operations and about beam losses, which were estimated from experience at other accelerator facilities. Additional calculations that were used to analyze specific shielding issues, such as the storage-ring ratchet wall, led to detailed designs. In accordance with the process adopted for approval of ALS project technical designs [Paterson and Lancaster, 1987], reviews were held to analyze the proposed shielding design, with pertinent recommendations from the reviews being incorporated into the final design. The shielding design for the injector complex (and by implication for the storage ring, as well) has been validated by radiation monitoring and personal dosimetry during commissioning in 1992. Monitoring data has shown that beam losses are lower than expected. In addition, commissioning experience with the injector has shown that some assumptions about accelerator operations are more conservative than necessary.

Beamlines are shielded in various ways. Bremsstrahlung shielding requirements are given in the ALS Beamline Design Guide and must consist of at least 10” lead in the longitudinal path and at least 2” lead beyond the extreme ray in the transverse direction. Anamorphic drawings documenting this are required and are reviewed and approved by the Beamline Review Committee when a new beamline is designed and whenever there are significant changes. Areas of synchrotron scatter are shielded as necessary with lead sheeting or other high-Z materials. Guidance for this has been developed for the hard X-ray beamlines. All shielding is reviewed and approved by EH&S Division Radiation Physics.

In sum, the ALS shielding is properly designed to limit occupational exposure to ALS staff and visiting scientists, as well as to the general public at the site boundary, under both normal and abnormal operating conditions.

Operation

Worker dose is monitored and a variety of real-time and integrated area dose measurements are taken to verify that design goals are being met. When elevated levels are found, the causes are investigated and mitigations instituted to assure that doses remain ALARA.

Strict configuration controls are in place to assure that all required shielding remains in place. These include: maintenance of controlled documentation for all shielding, design and review of any proposed changes to the configuration, independent verification of configuration before operation of beamlines, and on-going assessments of the effectiveness of shielding. These controls are all implemented through procedures.

3.4.1.2 Generation of Ionizing Radiation

For synchrotron-radiation facilities, bremsstrahlung (photons) and neutrons are the dominant ionizing radiation. Electrons lost from the accelerator beam generate bremsstrahlung when colliding with residual gas molecules in the accelerator vacuum chambers, with the chamber walls, or with other objects. Neutrons are generated, primarily by the giant photo-nuclear resonance, when the bremsstrahlung is absorbed by shielding.

Different levels of photon and neutron radiation are produced during different stages of operation. For example, in the case of the storage ring, the first stage of interest is the injection cycle. The efficiency of the injection process determines the average level of radiation. However, mis-steering the beam into the storage-ring or booster-to-storage ring transfer line will produce the most significant levels of radiation, so that special consideration must be applied in designing the shielding for the injection region. The next stage of operation after injection is stored beam in the storage ring.

Under normal conditions when beam is gradually lost over several hours, one would be concerned with the radiation produced by the interaction of electrons with atoms distributed in the storage-ring vacuum chamber (gas bremsstrahlung) and the radiation produced by the collision of electrons that are slowly lost from stable orbit with the vacuum chamber. Under accident conditions, one must evaluate the radiation produced when the entire electron beam is lost at a single point in the storage ring. The final stage of operation is dumping the electron beam when it has decayed and needs to be replenished. Similar scenarios exist for the booster synchrotron and the linear accelerator.

In general, shielding consists of concrete supplemented with lead and polyethylene. As a hydrogenous material, concrete is an effective material for neutron shielding. Polyethylene, another hydrogenous material, is used to provide additional neutron shielding. Concrete also protects against bremsstrahlung, but the required thickness is so large that it is not always practical to rely exclusively on concrete. Lead, which is a more effective bremsstrahlung shield material than concrete, is therefore used to provide additional protection.

The bremsstrahlung dose equivalent far exceeds the average neutron dose equivalent and will dominate the shielding [Swanson, 1985]. Hence, it is very probable that an adequate shield for bremsstrahlung would be more than adequate for neutrons, if concrete were used. However, if bremsstrahlung were shielded primarily by non-hydrogenous materials, such as lead or iron, the neutrons may not be adequately attenuated. The combination of concrete and lead is optimized to provide maximum shielding. Additional lead and polyethylene are used for local shielding in critical locations where space or geometrical constraints are an important consideration.

3.4.1.3 Conservative Initial Assumptions

The design values of the occupational and site-boundary exposures determined the thicknesses of the concrete shielding around the linear accelerator and linac-to-booster transfer line, the booster synchrotron, the booster-to-storage ring transfer line, and the storage ring for protection against both bremsstrahlung and neutrons [McCaslin, 1986; ALS, 1986; Swanson, 1987]. To protect against worst-case radiation exposures, pessimistic assumptions were made concerning the accelerator operating parameters and schedule. In addition, estimates of the number of electrons that would be lost from the beam during commissioning and during routine operation under these pessimistic assumptions were made based on experience at other accelerator facilities.

The conservative assumptions about accelerator operations include:

- The injection system would have to operate at 4 Hz, rather than the nominal 1 Hz, to fill the storage ring. This is the maximum frequency at which the injection system could be made to operate without major modifications to the hardware. However, the 4-Hz option would require a major upgrade of the magnet power-supply system.
- Injection would be carried out twice per eight-hour shift, rather than once. Depending on the lifetime of the beam after installation shutdowns, this assumption is not unrealistic.
- Injection would be to an accumulated current of 800 mA, rather than the nominal 400 mA.
- The ALS would be operational for 1095 eight-hour shifts per year. Typical actual operations (including Accelerator Physics and startup/tuning runs) are closer to 900 eight-hour shifts per year.
- Losses from the storage ring would occur at the maximum possible energy of 1.9 GeV, which has become the energy at which the storage ring operates most of the time.

- The injection system would be routinely "tuned-up" prior to an injection period. This operation was envisaged as one hour at one-fourth of the maximum intensity, followed by 15 minutes at full intensity. Experience has shown, however, that the injector complex can be brought into operation in five to 15 minutes.

Radiation hazards in the accelerator system result from capture losses in the linac, the booster, and the storage ring, from normal loss of the stored electron beam between fills, and from beam losses due to equipment malfunctions. The electron losses during injection repeat at the cycle rate of the system. Based on beam losses common at similar accelerator facilities, normal operational losses for each acceleration cycle were estimated to occur at the following places for a linac beam current of 8 $x10^{10}$ electrons per cycle:

- 4×10^{10} electrons per cycle are lost at the collimator in the linac-to-booster transfer line at 50 MeV.
- 0.8×10^{10} electrons per cycle are lost in the collimator and at the injection septum magnet at the booster at 50 MeV.
- 0.6×10^{10} electrons per cycle are lost around the booster at an average energy of less than 150 MeV during acceleration.
- 0.325×10^{10} electrons per cycle are recirculated and lost around the booster at 1.5 GeV after acceleration and extraction.
- 0.325×10^{10} electrons are lost per cycle in the booster-to-storage ring transfer line at an energy of 1.5 GeV.
- 0.325×10^{10} electrons are lost per cycle at the storage-ring injection point.
- 0.325×10^{10} electrons per cycle are lost around the storage-ring during injection at 1.5 GeV.
- The 3.3×10^{12} stored electrons per fill are eventually lost at 1.9 GeV.

Though operational parameters have changed since the original calculations were performed, the estimated radiation hazards resulting from these assumptions remain conservative.

3.4.1.4 Shielding Design

By means of empirical formulae, radiation exposures were calculated as a function of concrete thickness for these operating scenarios and estimated beam losses [McCaslin, 1986]. These calculations took into account the contributions of both uniform losses during normal operation and point losses during machine malfunctions. Shielding thicknesses were then found such that the general-public and laboratory-worker dose equivalents were acceptable. Figure 3-13 shows the design values for radiation exposure at various locations around the ALS for both uniform and point losses during machine malfunctions. Figures 3-14 and 3-15 show representative results for the booster synchrotron and the storage ring, respectively, and illustrate how the shielding thicknesses required to meet the design exposure specifications were determined. In all cases, the radiation shielding has been designed to be at least as thick as the minimum calculated requirements. Even with these safety factors, radiation monitoring constitutes an ongoing activity at the ALS, with extra shielding being employed where it is deemed necessary.

The ALS radiation shielding enclosures are constructed using both cast-in-place concrete structures and precast (removable) roof panels and wall blocks. Linac-vault walls are a minimum of 4 feet thick, as is the roof. Booster-synchrotron shielding is cast in place; the tunnel walls are a minimum of 2.5 feet thick; the roof is also 2.5 feet thick. Removable roof blocks are provided in three locations around the booster for access to equipment and for maintenance. The storage ring has a fixed (cast-in-place) inner wall and a removable (precast) outer wall section and roof section around its entire circumference to facilitate beamline egress from the tunnel. Storage-ring tunnel walls are nominally 1.5 feet thick; the roof is 1 foot thick. Figures 3-16, 3-17, 3-18, and 3-19 diagram the ALS shielding configuration for the ALS accelerators. In some locations, the storage-ring shield-wall and -roof thicknesses differ from the nominal values, and in some locations lead shielding is added (see Section 3.4.1.5).

To verify the performance of the ALS shielding, the Oak Ridge National Laboratory code MORSE was used to calculate the neutron dose equivalents in the facility and at the site boundary [Sun, 1989, 1991]. Use of the code required the construction of a geometrical model of the ALS facility that lends itself to numerical analysis on a computer. The model generated used circular approximations of the polygonal accelerators and included representative materials for the parts of the model. The code accounts for both direct neutrons penetrating the shielding and for "skyshine" neutrons scattered in the air [Swanson, 1988]. Additional contributions from intermediate- and high-energy neutrons were added as fixed percentages (25% and 2.5%, respectively) of that calculated with the code.

Output from MORSE gives the neutron dose equivalent as a function of position coordinates. Analysis of the output showed that two representative positions adequately describe the radiation hazard. A location 39 m from the ALS center along the line connecting the centers of the booster and storage ring and 6 m above the floor (i.e.. in the second floor) is the nearest to both the booster and storage ring and is representative of the location where the maximum occupational dose would be received. A second location 125 m from the ALS center on the south side and a height of 2.4 m represents the LBNL boundary where the maximum exposure of the general public would be received.

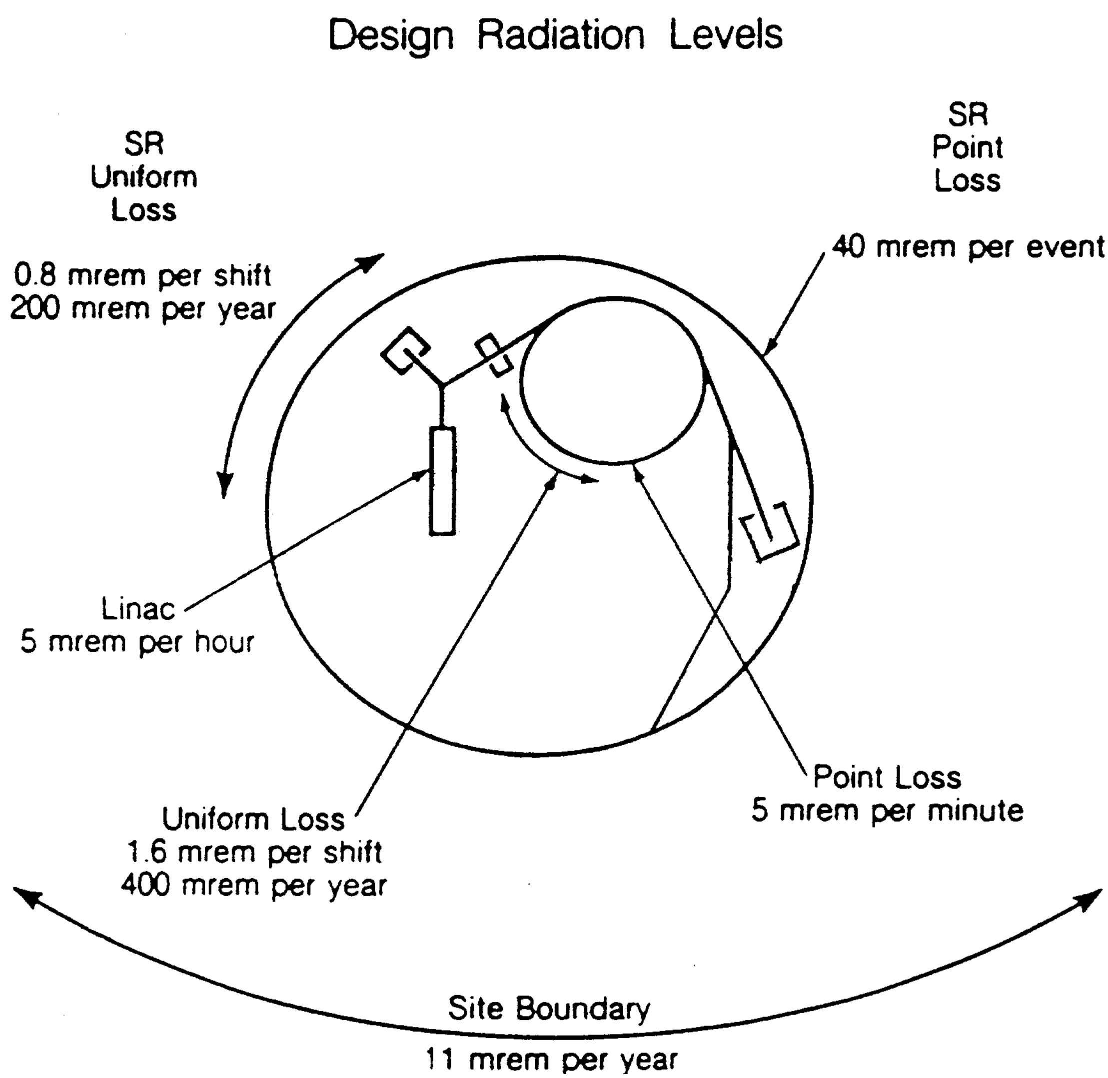

Figure 3-13. Schematic diagram the ALS accelerator area showing the design radiation levels for uniform and point losses at the storage ring, booster synchrotron, linear accelerator, and the LBNL site boundary.

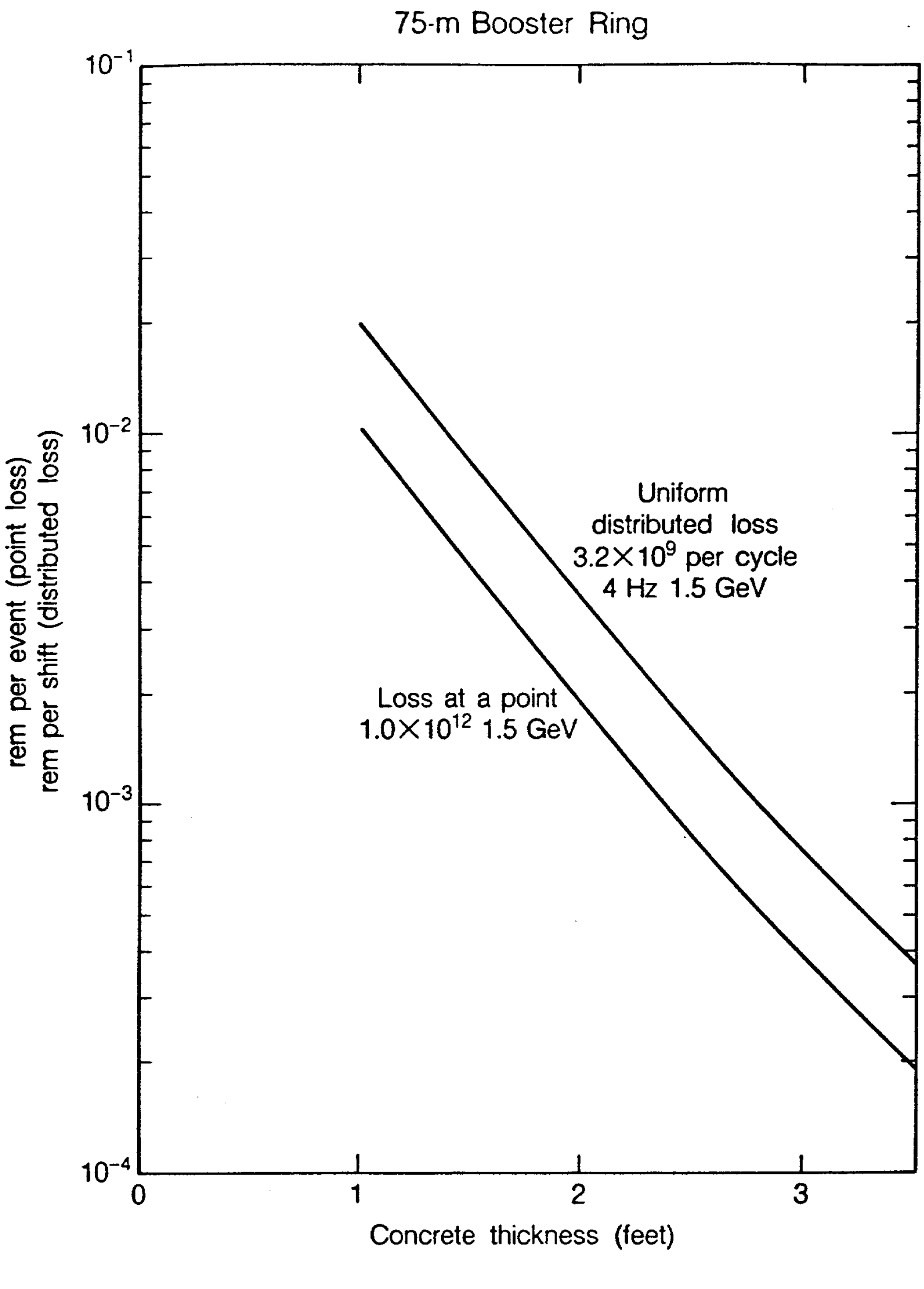

Figure 3-14. ALS booster-synchrotron occupational dose equivalent.

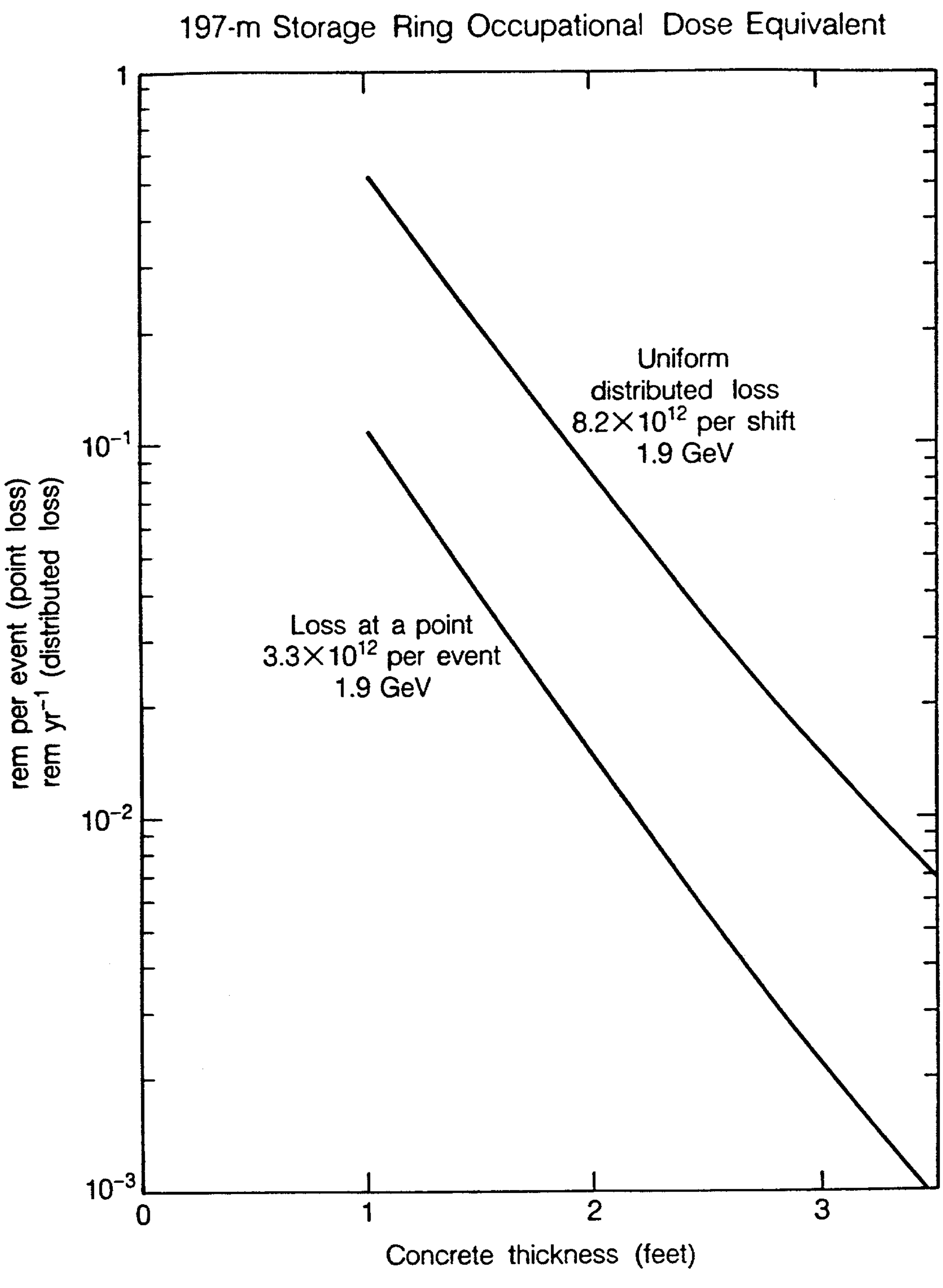

Figure 3-15. ALS storage-ring occupational dose equivalent.

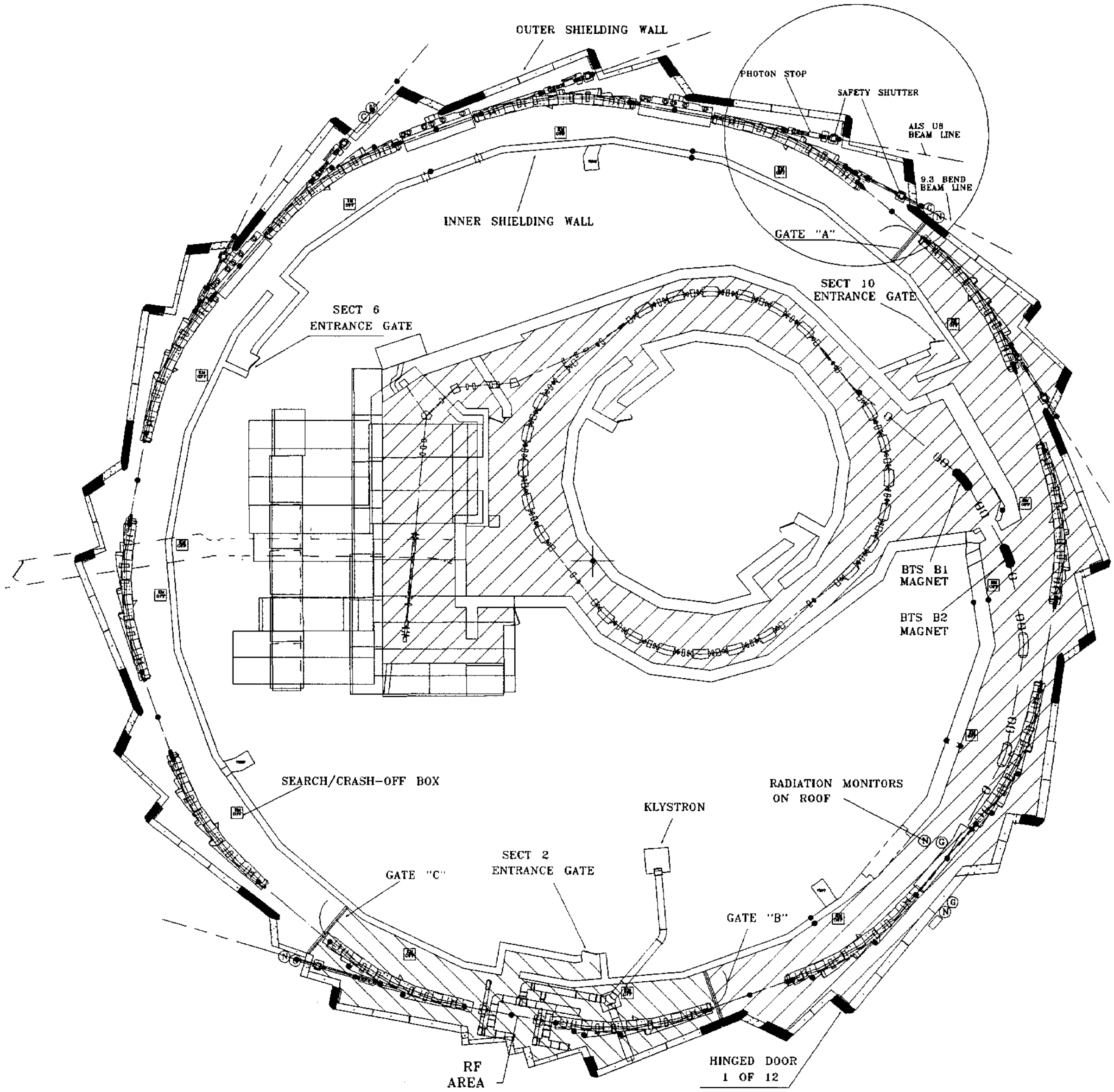

Figure 3-16. Schematic diagram of the ALS accelerator area showing the radiation shielding for the storage ring, booster synchrotron, and linear accelerator and the approximate locations of the neutron and photon detectors.

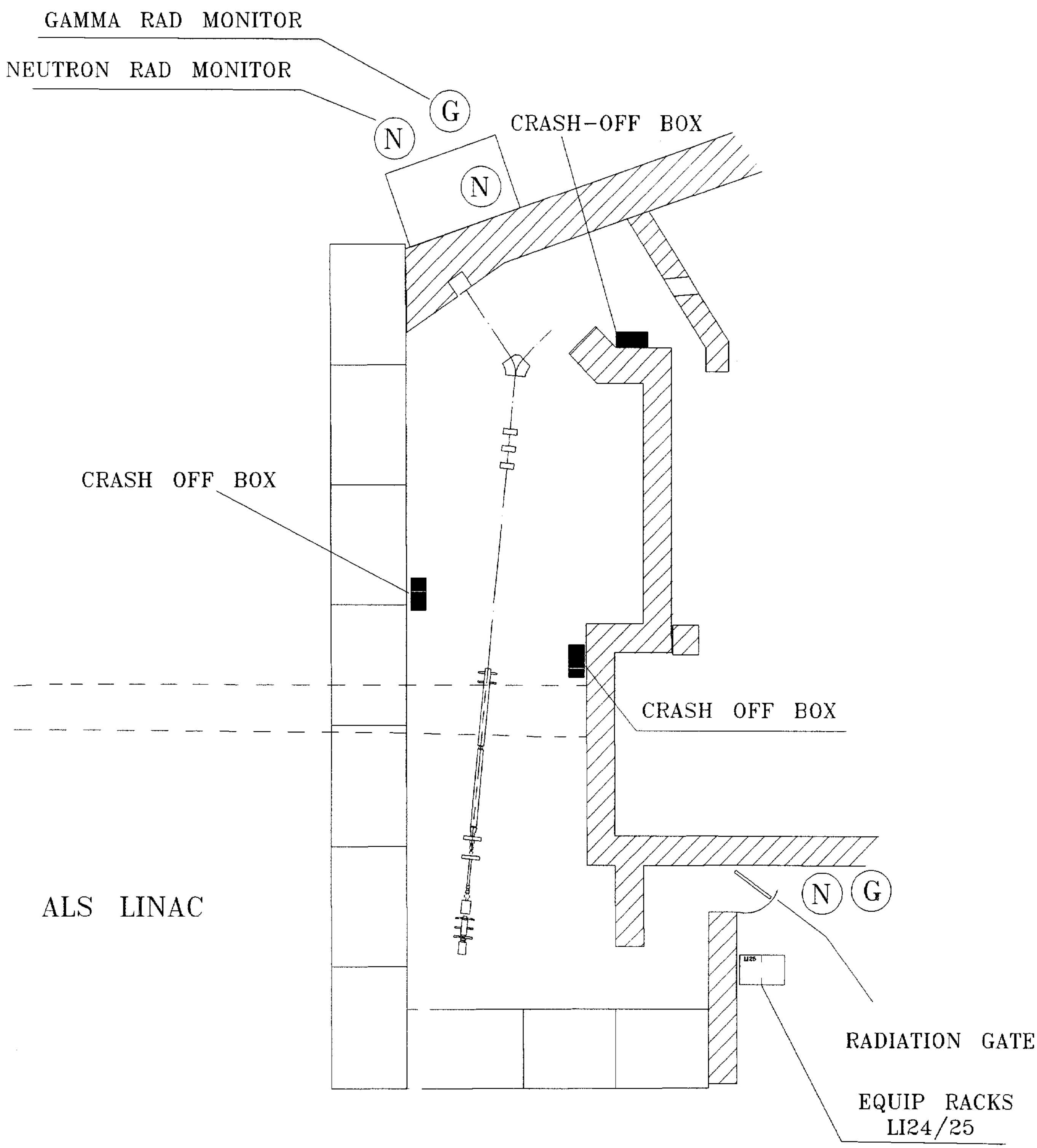

Figure 3-17. Detailed schematic diagram of the ALS linac area showing the radiation shielding and the locations of the radiation gate, the crash-off boxes, and the neutron (N) and photon (G) detectors.

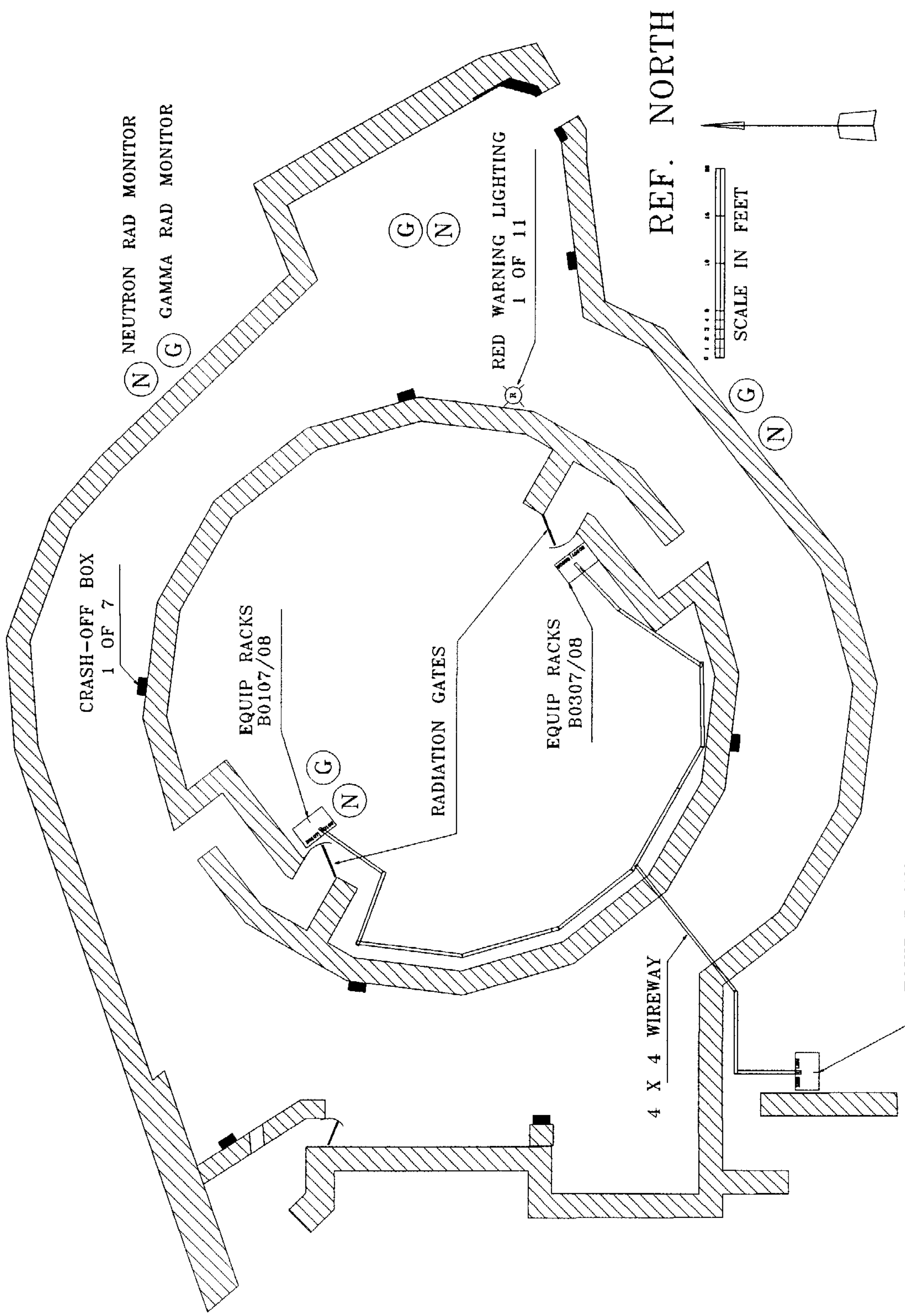

Figure 3-18. Detailed schematic diagram of the ALS booster-synchrotron area showing the radiation shielding and the locations of the radiation gates, the crash-off boxes, and the neutron (N) and photon (G) detectors

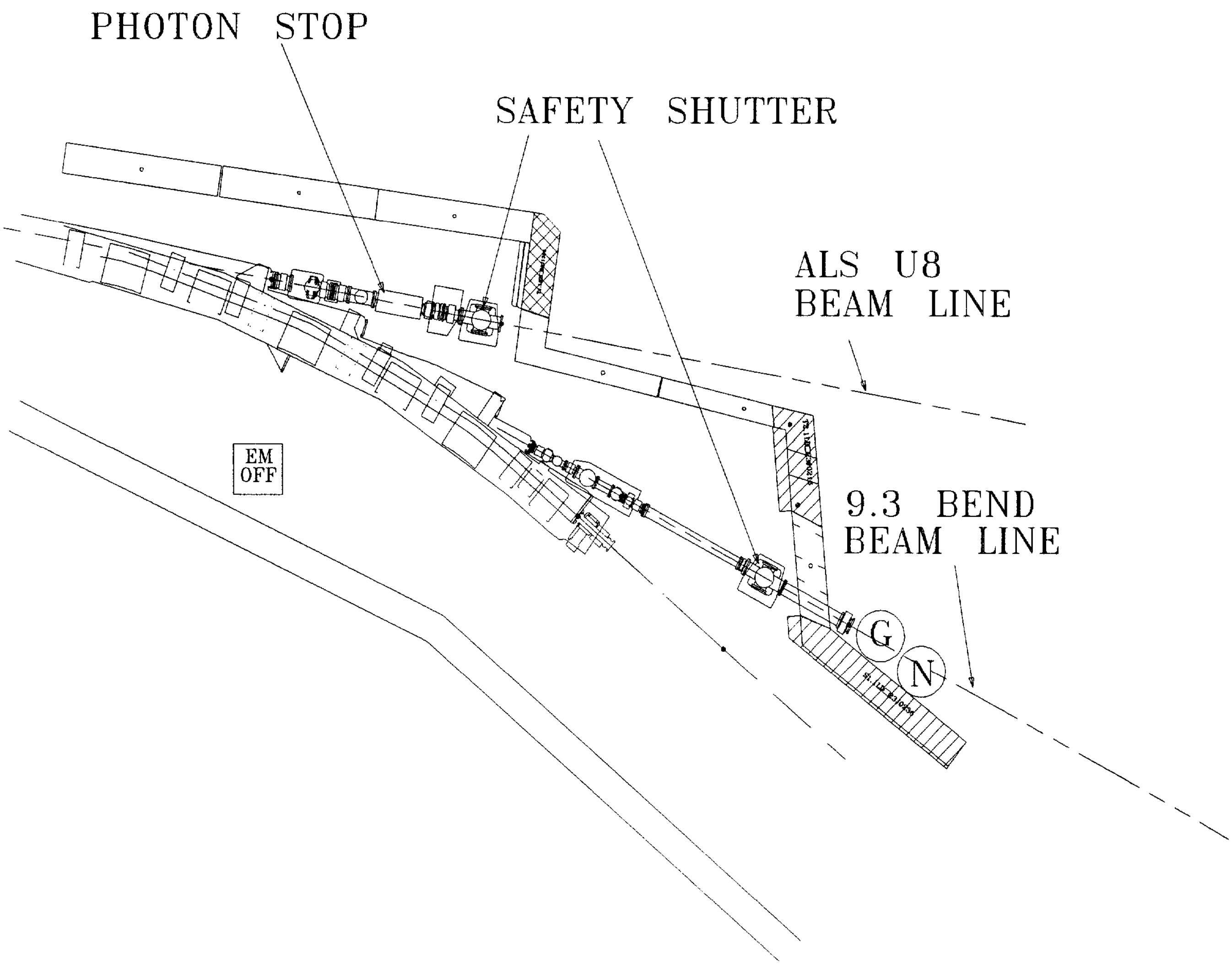

Figure 3-19. Detailed schematic diagram of one sector of the ALS storage-ring area showing the radiation shielding and the locations of the search/crash-off boxes (EM) and the neutron (N) and photon (G) detectors

Table 3-3a summarizes the calculated maximum neutron dose equivalents at these two locations separately for radiation from each section of the accelerator complex and gives the total annual neutron dose equivalent at these locations from all the sections. The maximum annual neutron dose equivalents are calculated to be 114 mrem/year (1.14 mSv/year) on the second floor for the 2000-hour occupational year and 30.2 mrem/year (0.30 mSv/year) to the general public at the site boundary.

The consequences of the conservative assumptions about accelerator operations are most noticeable in the accumulated dose at the site boundary. The site-boundary value exceeds the design goal and required administrative reporting level of 10 mrem/year. In light of this result, the MORSE calculations were repeated [Sun, 1991] using the expected operating parameters of the ALS of 400 mA storage-ring current (rather than 800 mA), injection pulse rate of 1 Hz (rather than 4 Hz), and 8760 annual hours of operation (rather than 8760 hours). These changes result in a reduction factor of 0.086 that can be applied directly to the dose equivalents in Table 3-3a, as shown in Table 3-3b, giving a maximum environmental dose equivalent at the site boundary of 2.65 mrem/year (26.5 μSv/year), well below the current administrative reporting level (and design goal) of 10 mrem/year. In addition, some local shielding near the linac, collimators, and other components, and the shielding effect of equipment, furniture, partitions, etc. inside the ALS building were not considered. Consequently, the calculated dose equivalents are higher than those expected to be observed. It can therefore be concluded that the ALS shielding was adequately designed and complies both with radiological protection and environmental dose limits.

A potential additional factor to consider is that interaction of bremsstrahlung radiation with molecules in the air can generate radioactive isotopes by means of photonuclear reactions. The principal products are nitrogen-13 and oxygen-15 from nitrogen-14 and oxygen-16, respectively [McCaslin, 1990a; Donahue, 1991a]. However, the ALS building, which is equipped with air conditioning in the storage ring tunnel and the experimental areas, affords sufficient mixing, dilution, and time delay to reduce exposure levels from these short-lived isotopes to less than 0.1 mrem/year in the building and less at the site boundary.

Table 3-3a. Maximum Annual Dose-Equivalent Rates for the ALS for the Most Conservative Operating Conditions

Maximum occupational dose equivalent (D.E.) on the second floor (39 m from ALS center and 6 m above ground floor, 2000-hour/year)					
Quantities	**Linac +LTB**	**Booster ring**	**BTS**	**Storage ring**	**Units**
D.E. from MORSE	4.30×10^{-5}	1.04×10^{-5}	1.33×10^{-6}	3.22×10^{-8}	mrem joule^{-1}
Annual energy loss	1.39×10^{6}	2.88×10^{6}	1.95×10^{5}	6.23×10^{5}	joule year^{-1}
Calculated D.E. rate	59.8	29.9	0.259	0.0200	mrem year^{-1}
Modified[a] annual D.E.	76.2	38.2	0.33	0.0255	mrem year^{-1}
Total annual D.E.			114		mrem year^{-1}

Maximum environmental dose equivalent (D.E.) (125 m from ALS center and 2.4 m above ground floor, 8760 hour/year)					
Quantities	**Linac +LTB**	**Booster ring**	**BTS**	**Storage ring**	**Units**
D.E. from MORSE	2.74×10^{-6}	5.46×10^{-7}	1.24×10^{-8}	2.08×10^{-8}	mrem joule^{-1}
Annual energy loss	6.09×10^{6}	1.26×10^{7}	8.57×10^{5}	2.72×10^{6}	joule year^{-1}
Calculated D.E. rate	16.7	6.88	0.106	0.0566	mrem year^{-1}
Modified[a] annual D.E.	21.3	8.78	0.135	0.0722	mrem year^{-1}
Total annual D.E.			30.02		mrem year^{-1}

[a]Including 25% for intermediate-energy neutrons and 2.5% for high-energy neutrons.

Table 3-3b. Maximum Annual Dose-Equivalent Rates for the ALS for Realistic Operating Conditions

Maximum occupational dose equivalent (D.E.) on the second floor (39 m from ALS center and 6 m above ground floor, 2000-hour/year)					
Quantities	**Linac +LTB**	**Booster ring**	**BTS**	**Storage ring**	**Units**
D.E. from MORSE	4.30×10^{-5}	1.04×10^{-5}	1.33×10^{-6}	3.22×10^{-8}	mrem joule^{-1}
Annual energy loss	1.22×10^{5}	2.52×10^{5}	1.07×10^{4}	5.44×10^{4}	joule year^{-1}
Calculated D.E. rate	5.15	2.62	0.0277	0.00175	mrem year^{-1}
Modified[a] annual D.E.	6.67	3.34	0.029	0.0223	mrem year^{-1}
Total annual D.E.			10.0		mrem year^{-1}

Maximum environmental dose equivalent (D.E.) (125 m from ALS center and 2.4 m above ground floor, 6000 hour/year)					
Quantities	**Linac +LTB**	**Booster ring**	**BTS**	**Storage ring**	**Units**
D.E. from MORSE	2.74×10^{-6}	5.46×10^{-7}	1.24×10^{-8}	2.08×10^{-8}	mrem joule^{-1}
Annual[a] energy loss	5.33×10^{5}	1.10×10^{6}	7.50×10^{4}	2.38×10^{5}	joule year^{-1}
Calculated D.E. rate	1.46	0.602	0.00927	0.00495	mrem year^{-1}
Modified[b] annual D.E.	1.86	0.768	0.0118	0.00631	mrem year^{-1}
Total annual D.E.			2.65		mrem year^{-1}

[a]Calculation with storage-ring current 400 mA, injection rate 1 Hz, and use factor 0.7.
[b]Including 25% for intermediate-energy neutrons and 2.5% for high-energy neutrons.

3.4.1.5 Present Shielding Configuration

Linac

Calculation of the dose rates expected during linac commissioning [McCaslin, 1990b] verified that the shielding was adequate, except for a region behind the linac beam dump, where rates were potentially significantly higher. To protect against the additional radiation, shielding blocks with total dimensions 10-feet wide by 10-feet high by 4 feet thick were placed outside the existing shielding wall behind the beam-dump area.

Storage Ring

The storage-ring shielding is ratcheted with side walls approximately tangential to the storage ring and transition walls perpendicular to the beamlines, which radiate tangentially from the storage ring. In addition, there are special shielding requirements in the injection area. In some locations, the storage-ring shield-wall and -roof thicknesses differ from the nominal values enumerated in Section 3.4.1.5, and in some locations lead shielding is added. The design goals for radiation exposure are 250 mrem/2000-hour work year (0.13 mrem/hour) for normal operation and 40 mrem/event for accidental loss of beam. It should be noted that the details of the storage-ring ratchet wall are not an issue for exposure to the general public at the site boundary, since the linac dominates the dose equivalent at this location.

The details of the present configuration of radiation shielding have evolved, but the design remains based on the calculations described in Sections 3.4.1.2 and 3.4.1.3. The evolution reflects in-depth examination of specific radiation issues, the outcomes of design and safety reviews, and the results of radiation monitoring during commissioning of the linac and booster synchrotron.

During the course of the ALS construction project, several internal and external reviews were held that included the shielding design, including formal DOE Safety Reviews in November 1989 [ALS, 1989d] and September 1991 [ALS, 1991b]. A major Conceptual Design Review was held in July 1990 [Melczer, 1990a], with a follow-up review in September 1990 [Melczer, 1990a]. The outcomes of these reviews led to the specific shielding configuration shown in Figure 3-20 [Matuk, 1991]. In addition, calculations were used to investigate specific radiation issues and to validate shielding-design features, as indicated by the references in the following paragraphs:

(1) The transition walls are designed for the worst-case scenario of a zero-degree beam perpendicularly penetrating the transition wall [Swanson, 1986; Melczer, 1991a; Donahue, 1992a; Donahue 1993]. Outside the injection region, the storage-ring transition wall comprises 1.5 feet of concrete, a floor-to-ceiling lead shield 3 inches thick, and a 9.2-inch band of lead, also 3 inches thick, centered at the orbit plane of the electron beam. The transition walls at insertion-device ports comprise monolithic, interlocked, hinged shielding blocks.

(2) To provide clearance for the insertion-device beamlines, the thickness of the side walls between the transition walls facing insertion-device and bend-magnet ports was reduced to 1 foot [Swanson, 1987; Melczer, 1991a; Melczer, 1991b]. All storage ring side walls have provision for 1 inch of lead shielding at a future date, should radiation surveys indicate a requirement for additional shielding against photons.

(3) To provide additional protection against injection loss, additional storage-ring wall and roof shielding is provided downstream of the region where electrons are injected from the booster synchrotron into the storage ring [Donahue, 1991b]. The thickness of the storage-ring shielding roof blocks is increased to 1.5 feet near the booster-to-storage ring transfer line, and the thickness of outside walls normally 1.5 feet and 1 foot, respectively, are increased to 2 feet and 1.5 feet, respectively, in much of this area. Inside walls are 3.3 feet thick in the injection area. Side walls in the storage-ring injection area have 2 inches of lead shielding, and transition walls have a floor-to-ceiling lead wall 4 inches thick and a 3-inch thick band of lead 9 inches high centered on the electron orbit plane.

(4) There are penetrations in the storage-ring walls for ventilation (HVAC) [Sun, 1990; Donahue, 1991c]. There is already sufficient shielding provided by the storage-ring components (such as the magnets) outside the injection area. Monitoring will be used to determine if additional lead shielding is needed in the injection area.

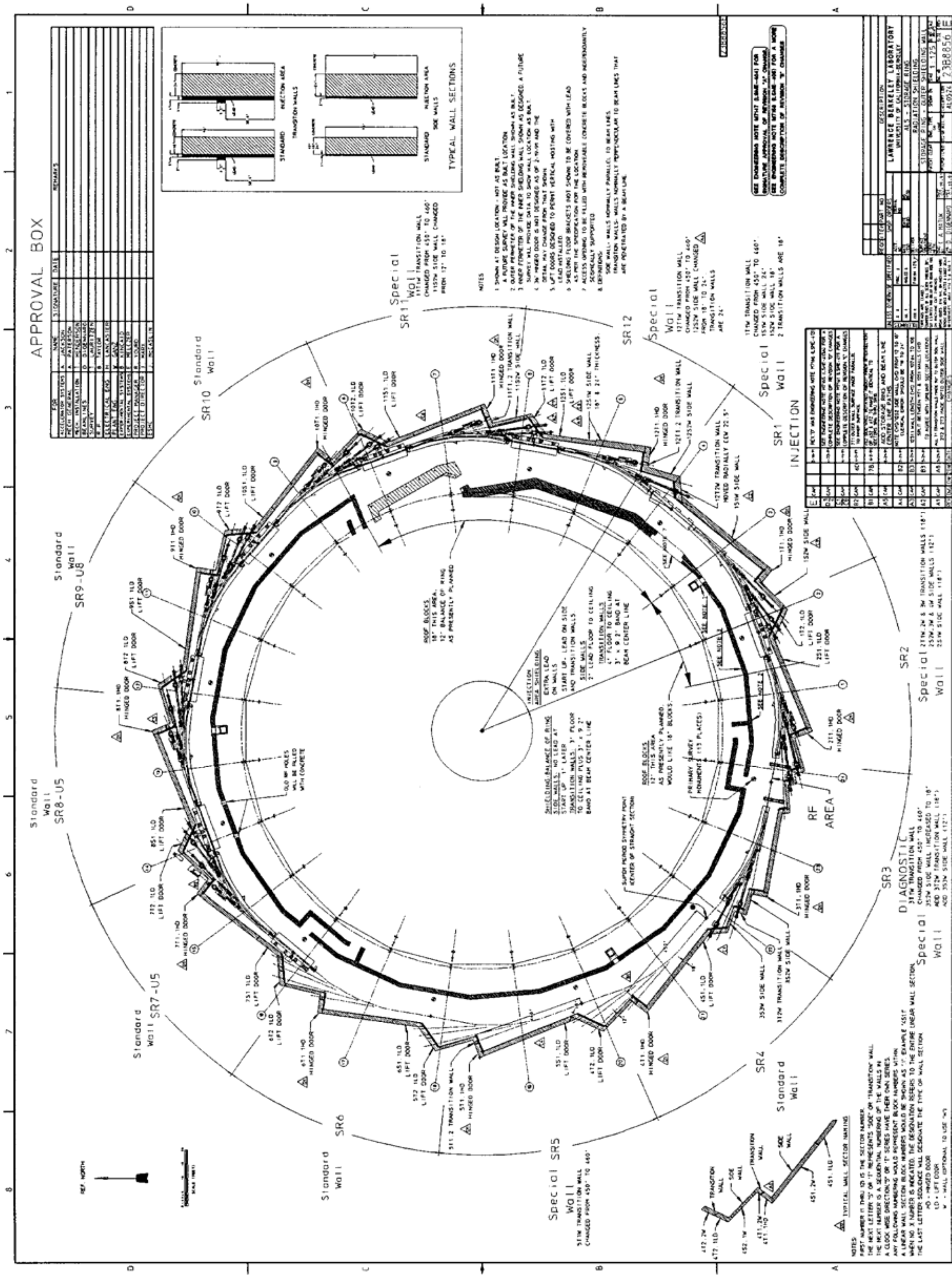

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Figure 3-20. ALS storage-ring shielding configuration

3.4.1.6 Validation of the ALS Shielding Design by Injector-Commissioning Experience

Commissioning of the accelerator systems started in October 1990 with the linac. Commissioning of the booster began in May 1991 and commissioning of the entire accelerator complex continued through to April 1993. The initial stages of this activity took place at a time when construction and installation work was ongoing.

Radiation monitoring at the site boundary and in the ALS building, as well as personal dosimetry data, during the injector commissioning show that radiation levels are, in general, lower than expected. This not only confirms the adequacy of the shielding, but suggests that electron beam losses are lower than estimated. Assuming the same pattern holds for the storage ring, the conclusion is that the reduced radiation levels associated with the lower beam losses makes operation of the ALS even less hazardous.

3.4.1.7 Bremsstrahlung Radiation in the Beamline Areas

ALS beamlines require holes to be opened in the storage-ring shielding. In addition to the synchrotron radiation, the holes will allow hard bremsstrahlung to pass through to the experimental floor. Based on safety requirements currently in force at the National Synchrotron Light Source, initial guidelines for designs for beamlines were developed [Warwick, Melczer, Perera, and Heimann, 1990]. Installation of beamlines that satisfy these requirements is now in progress. Radiation shielding designs are subject to design and safety reviews. Typical among the major reviews for LBNL-engineered beamlines are a Front End Radiation Safety Requirements Review that was held in February 1991 [Johnson, 1991] and a Beamlines Preliminary Design Review that was held in September 1992 [DiGennaro, 1992]. All beamline designs, both LBNL- and user-engineered are subject to review by the Beamlines Review Committee, as described in Section 3.3.6. Calculations were used to investigate specific radiation issues and to determine criteria for shielding designs [Swanson, 1986; Melczer, 1990b; Melczer, 1991c; Donahue, 1992b; Donahue, 1993]. During beamline commissioning, radiation monitoring will be used to determine the need for supplementary shielding.

The shielding design in the beamline area is based on the following factors:

- Apart from the hole in the shielding, the storage-ring shield wall is assumed to give adequate protection against all radiation from the ring.

- In normal operating mode, a personnel safety shutter (PSS) that is an integral part of the bremsstrahlung collimation system or bremsstrahlung shield will close the hole during storage-ring injection and when the beamline is not in operation.
- The PSS for a beamline may be left open during Top-Off mode injection if that beamline is Top-Off mode qualified. A Top-Off mode qualified beamline meets the following requirements:
  - a formal electron tracking analysis has been performed to identify any conditions under which an electron bunch might travel further than an established safe point on a beamline;
  - apertures used to calculate those above conditions are under formal configuration control; AND
  - a combination of interlocks has been installed and tested to ensure safe operation of the Top-Off mode qualified beamline.

Prior to running Top-Off mode qualified beamlines in Top-Off mode, the required interlocks must be active.

- The possibility that the shutter will provide inadequate shielding against neutrons will be dealt with if neutron radiation is observed; it has not been a problem at other facilities.
- All parts of the shutter and any extra shielding associated with it will be inside the shield wall.
- The shutter will be fail-safe and will be positively sensed in the closed position.

When the shutter is open, bremsstrahlung passes through to the experimental floor, requiring additional shielding at certain locations and the establishment of exclusion areas by means of physical barriers or administrative procedures. In many cases, the physical barrier will be the beamline vacuum chamber itself. Beamline design factors pertaining to the open-shutter condition include:

- Analysis at the National Synchrotron Light Source [NSLS, 1982] indicates that the bremsstrahlung yield down a beamline over one year of normal operation is greater than that from a single worst-case vacuum accident. Protection against normal operation is therefore the basis of the shielding design.
- All lines of sight from the bremsstrahlung source will be collimated or blocked by shielding to contain the bremsstrahlung inside the portion of the beamline to which access is

excluded, except that under controlled testing conditions lines of sight where equivalent protection is designed to reduce the maximum potential dose to that of a Radiation Area (> 5mrem/hr, < 100mrem/hr) may be protected by roping and posting. Equivalent protection will include software limits on stored current, personnel barriers, off-shift running, and reduced injection frequency.

- The region of the experimental floor within the collimated direct bremsstrahlung beam will be an exclusion zone. Physical barriers will keep all body parts of personnel from entering this zone. Where the beamline vacuum chamber does not contain the bremsstrahlung, external physical barriers (such as secured lexan exclusion zones) or interlocks will be required, except that under controlled testing conditions lines of sight where equivalent protection is designed to reduce the maximum potential dose to that of a Radiation Area may be protected by roping and posting. Equivalent protection will include software limits on stored current, personnel barriers, off-shift running, and reduced injection frequency
- Bremsstrahlung can be scattered outside the collimation zone by massive objects (mirrors, flanges, etc.). Scattered radiation will be dealt with as required during commissioning the beamline.

3.4.1.8 Validation of Personnel Safety Shutter

A personnel safety shutter includes an 8-inch block of tungsten, which is designed to provide bremsstrahlung attenuation equivalent to the transition wall shielding. The shielding performance of the personnel safety shutter in Beamline 8.0 was tested by closing vacuum valves in the storage ring and observing the resulting radiation at the end of representative location at the end of a beamline and outside the shielding [Collins, 1993a]. This scenario simulates the worst case accident, a thin-target source directly irradiating a beamline.

In the first part of the test, a vacuum valve at the upstream end of the straight section in Sector 8 of the storage ring was closed during injection of 7 mA of current from the booster synchrotron. The valve created a thin-target source of bremsstrahlung that was most intense in the straight section of Sector 8 and hence illuminated Beamline 8.0. The personnel safety shutter attenuated the radiation to less than 1 mrad/hour photons and less than 0.1 mrem/hour neutrons at the end of the beamline.

In the second part of the test, a vacuum valve in Sector 3 of the storage ring was closed, again creating an intense source of bremsstrahlung in the Sector 3 straight section. At 0.8 mrad/hour photons and less than 0.1 mrem/hour neutrons, the results of measurements outside the Sector 3 shielding (there is no Beamline 3.0) were comparable to those made for Sector 8.

The acceptance criterion for the personnel safety shutter is that it provide bremsstrahlung attenuation equivalent to the shielding. These test results satisfy this criterion, indicating that the performance of the personnel safety shutter is acceptable.

3.4.1.9 Shielding for the Beam Test Facility

Shielding materials and thicknesses required for the BTF, which have been calculated assuming very aggressive operation of the linac, are adequate to limit occupational worker exposure to l00 mrem/year [Donahue, 1992d]. For a normal operating schedule of 1000 hours/year, this corresponds to an hourly dose limit of 0.1 mrem/hour. The shielding comprises concrete walls 7 feet thick in most locations and concrete roof blocks 4 feet thick supplemented with lead and polyethylene where necessary. The concrete shielding is 8.25 feet thick in front of the BTF beamline, where a beam dump is located. Locations of the lead and polyethylene include 4 inches of lead on the roof above collimators and scrapers, 7 inches of lead and 21 inches of polyethylene on the roof above the beam dump, 3.2 inches of lead and 14 inches of polyethylene between the beam dump and the entrance labyrinth, 4 inches of lead by the first bend magnet in the BTF vault, and 3 inches of lead by the bend magnets in the linac cave. Figure 3-21 shows the BTF layout and shielding.

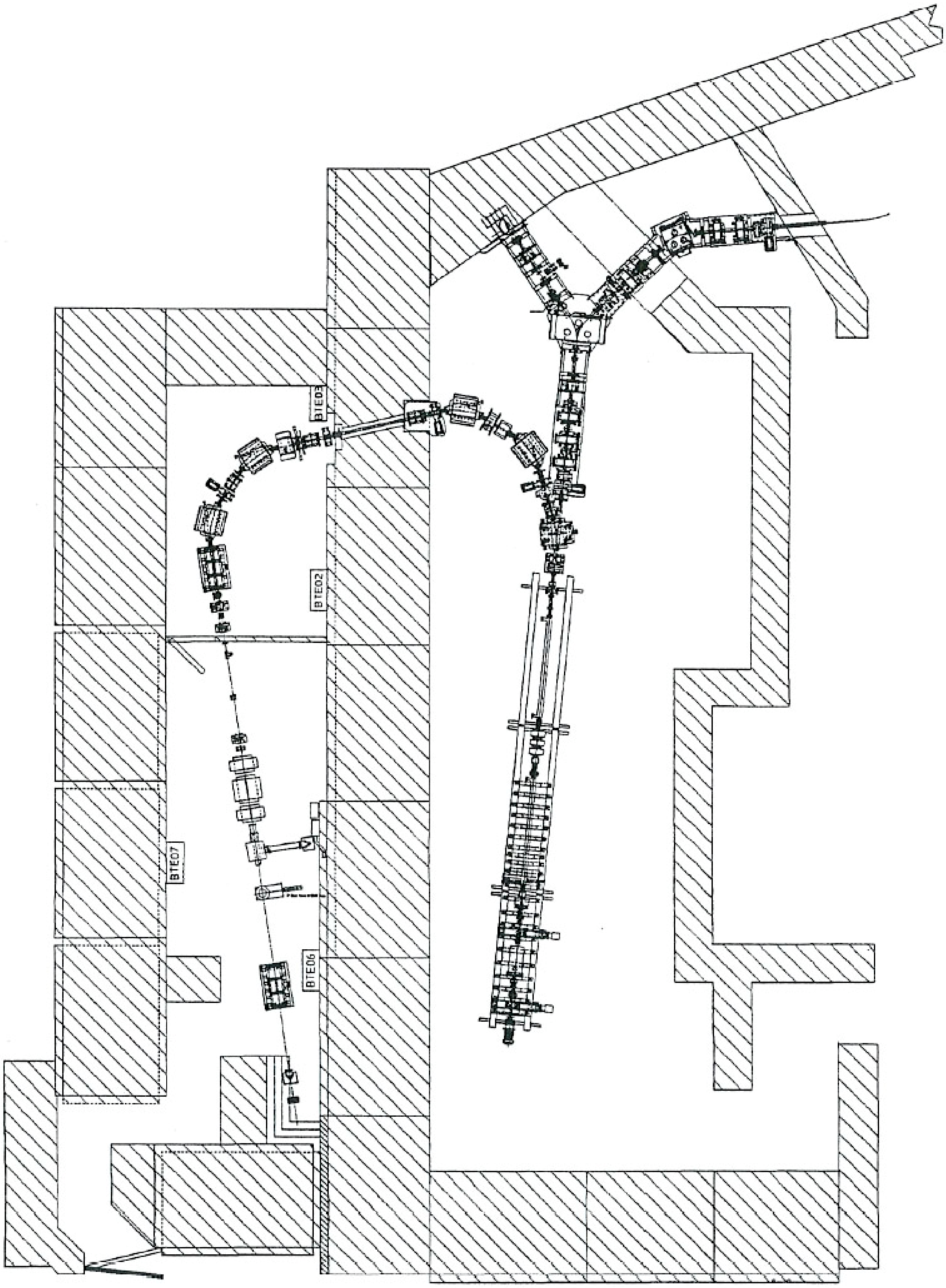

Figure 3-21. Detailed schematic diagram of the Beam Test Facility area showing the radiation shielding and the locations of the radiation gates and the crash-off boxes.

3.4.2 Radiation Safety System

The radiation safety system is the major control system responsible for personnel radiation safety at the ALS. The elements of this system comprise the interlock logic, operator station, and status displays associated with each component of the overall ALS architecture. All of the major accelerator subsystems are associated with one or more radiation safety system controller(s).

3.4.2.1 Design Considerations

A very important factor in designing the ALS radiation safety system was future component availability for maintenance spares and circuit expansion. With typical accelerator lifetimes of 30 to 50 years or more, circuit components with a high probability of being manufactured in the distant future narrowed the design process but the foremost factor in the component selection process was component reliability, failure modes, and predictability.

For all of these reasons, and others, a 24-volt direct current system using electrical-mechanical relays to perform the logic functions was selected. The 24 volts is well below the 50 volt level set by OSHA for hazardous working conditions requiring lock-out/tag-out or special safety equipment for "live" work. This voltage is also widely used in industrial and military control circuit designs, thus a large number of components are available from manufacturers to solve design problems. Because of the proliferation of relays in control and safety circuits dating back to the early part of this century, a long history exists regarding their ruggedness, reliability, and predictability. Solid state devices introduced in the late 1950's, quite often become obsolete and unavailable, and tend to fail in the unsafe (shorted) mode. At the time this system was designed, programmable devices often had software quality assurance and control problems. The broad worldwide use of electrical-mechanical relays and large number of manufacturers tends to guarantee future availability.

Except for short lengths at interlocked radiation monitors and beamline safety shutters, radiation safety system cables are routed in separate enclosed wireways or conduit apart from other accelerator wiring and not allowed in open ladder trays. An audio intercom system uses #20 AWG shielded twisted pair and a video system uses RG-59 coax cables, otherwise, all interlock cables are specified to have a minimum wire size of number 16 AWG, stranded, tinned copper, with an abrasion resistant, flame retardant, low smoke insulating jacket, and be listed and approved by the Underwriters' Lab with a type TC (tray cable) rating.

All switch and relay contacts have a minimum 5 amp rating at 24 volts dc and all relay coils must operate at 75 percent of their coil voltage rating. In an effort to prevent accidental wiring errors or tampering all radiation safety equipment, cabinets and junction boxes are locked. All interlock chains are tested annually and all radiation monitoring equipment is also calibrated on an annual basis.

3.4.2.2 Access Control

The system permits three types of access control. The first being no access allowed during accelerator operations. Second is controlled access inside the shielding under certain conditions. After an area inside the shielding has been searched and secured, controlled access can be allowed back into that area. Accelerator operations are inhibited and guaranteed by requiring each person entering under controlled access to take a key from a "controlled access key cache" located outside each entrance gate. This key cache has redundant interlocks preventing accelerator operation until all keys are returned. This type of access control does not require the accessed area(s) to be searched and secured after a controlled access has been allowed. Any uncontrolled, inadvertent access or activation of any emergency crash-off push button switch in a previously searched area will interrupt accelerator operations and require a new search and secure of that area. The third type of access is uncontrolled access and occurs when the accelerator is shut down for modifications or maintenance and the access gates entering the shielding are propped open.

An audio and color video intercom system links the six shielding entrance gates with the control room and is used for controlled access activities. A commercial video and audio switching unit made by Pelco Inc. is located in the control room along with a color monitor and speaker/mic assembly.

3.4.2.3 Search and Secure

The search of a given area of the accelerator is done using keys and key-switches. See Figure 3-22 for a schematic of these areas. The "search keys" are removed from key-switches in the main control room. Removal insures the safety of the search party. Areas to be searched have key switches that mate with the search keys. These key-switches must be reset in a prescribed sequence, and in some cases, an extra push button is installed whereby two switches must be operated in tandem, thus forcing a two person search. Accelerator operation is inhibited until the search keys are returned to the control room and turned to the operate position and a 60 second time delay occurs. During this 60 second delay, normal white lighting inside the shielded radiation areas is immediately turned off, red lighting is turned on and a two tone audible alarm inside the shielding is sounded. Backlit status indicator signs located in numerous locations change from "safe" to "operational" and after the 60 seconds has timed out, the indicator signs change to "unsafe leave area", the audible alarm ceases and red flashing beacons outside the entrance gates commence flashing. Controlled access entry turns the normal white lighting back on and turns the red lighting and flashing beacons off. After the person(s) has exited from a controlled access and returned the keys to the key cache, the 60 second time delay sequence is re-initiated with the audible and visual warnings as described above.

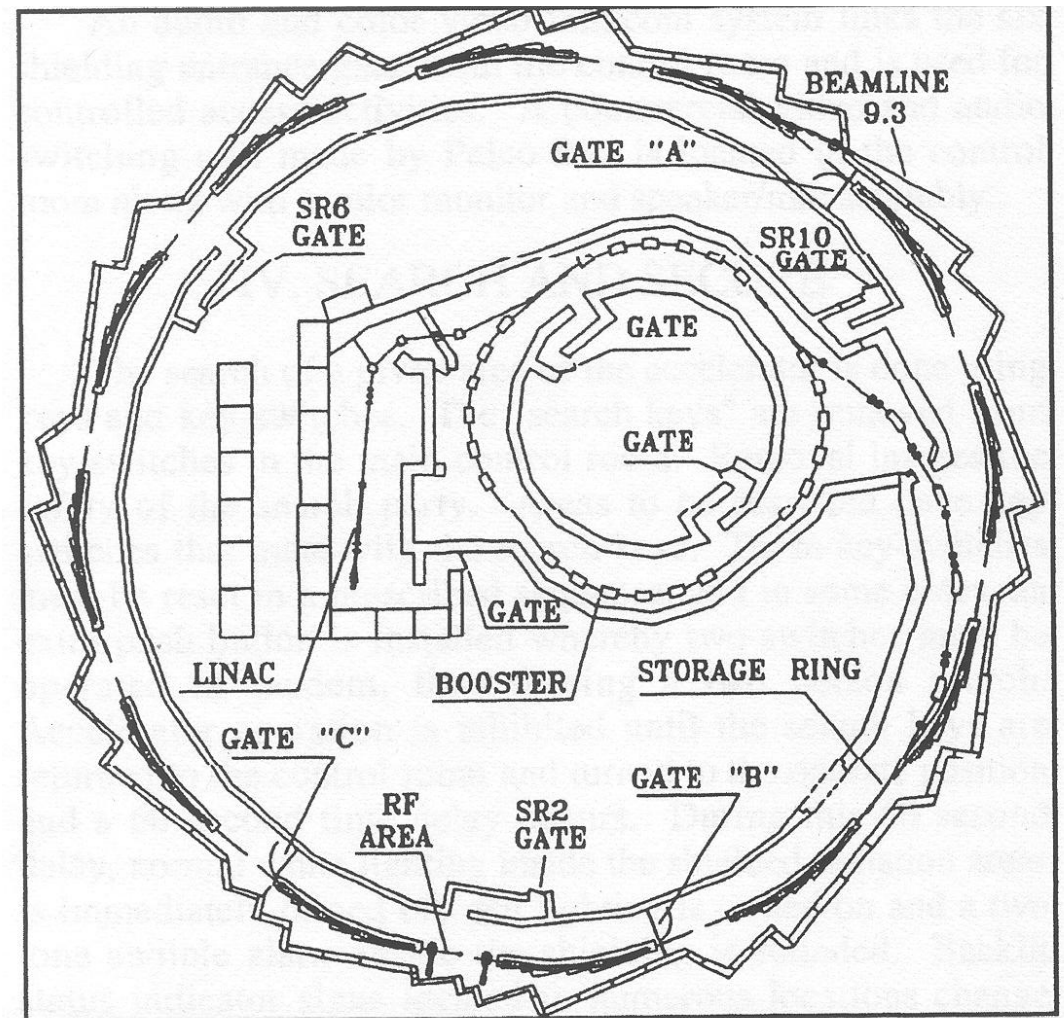

Figure 3-22 – Schematic Diagram of Accelerator Access

3.4.2.4 System Description

The interlock system consists of three main interlock chains each having a number of sub-chains; all with redundancy throughout. The first of the three main interlock chains is the linac chain which controls the 120 KeV electron gun as well as the 50 MeV linac. Both have redundant interlock controls. The electron gun, for example, has its ac main interrupted and the 120kV power supply external interlock turned off should an interlock be violated. The linac chain has three sub-chains capable of interrupting the electron gun/linac operation. A description of these sub-chains is as follows:

a) Because of thin shielding in the booster-to-storage ring beam transport area, a portion of the storage ring (between internal gates "A" and "B") is interlocked as a sub-chain to the linac chain, and occupancy of that portion of the storage ring is not allowed while the linac is operational. Shielding is adequate when backed up with these interlocks. These same interlock devices (gate/door micro switches, search switches, crash-off switches, etc.) in this storage ring area are also a part of the storage ring interlock chain described later. After the storage ring is filled and operated in a "stored beam" mode, and the linac is shut down, occupancy of this area is still prohibited because of the radiation produced by the stored electron beam. Access to this area is only permitted when both the linac and the storage ring are shut down. Controlled access to this area inhibits operation of both the linac and the storage ring.

b) The second sub-chain controlling the linac chain is the booster interlock chain. Originally the booster interlock chain was to be a separate interlock system allowing access to the booster while limited linac operations were permitted. Shielding design changes mandated the booster interlock system control the linac operation. Access to the booster through either of its two entrance gates or activation of any booster crash-off push button switch will inhibit the linac operation. As with the linac chain having sub-chains, the booster has a sub-chain consisting of active radiation monitors that eventually control the operation of the linac. Should gamma or neutron radiation above a preset trip level be detected outside the shielding, the radiation monitor will interrupt the linac operation indirectly via the booster chain. The tripped radiation monitor interlock is latched off and requires control room investigation and manual reset in the area of concern. These radiation monitors are commercially manufactured by Health Physics Instruments Inc. and are designed for pulse operations. In addition to an active interlock output, they have a number of features including analog and digital output signals for remote data collection of the radiation being detected.

c) The third sub-chain of the linac is another radiation monitoring system using the same type of detectors as described above for the booster sub-chain. These detectors are located in areas just outside the linac shielding and if radiation above a preset trip level is detected, the linac operation will be inhibited. As with the booster radiation monitoring chain, the tripped monitor is latched off and requires control room investigation and reset before operations can resume.

The second main ALS interlock chain is the storage ring chain. It eventually becomes an input along with the third main ALS interlock chain (storage ring fill/run described later) to control the storage ring RF system and the booster-to-storage ring electron beam transport line B1 and B2 bending magnets. The inner storage ring shielding wall has three controlled access entrance gates. Inside the shielding are three internal gates dividing the storage ring into three zones. The outer wall has 12 hinged concrete doors for maintenance access. All of these doors and gates are interlocked. The operation of the storage ring chains and sub-chains is as follows:

a) The storage ring area between internal gates "A" and "B" as discussed earlier is a sub-chain of the linac and storage ring. The function of the interlock devices bounded by the two internal gates "A" and "B" are summed as a sub-chain at the storage ring sector 10 entrance gate safety racks and becomes an input for the main storage ring chain at the storage ring sector 6 entrance safety racks (as well as the linac described above).

b) The storage ring has two RF cavities installed in the straight section between sectors 2 and 3 that are powered by a 300kW klystron via a wave guide structure. To allow testing of this RF system and uncontrolled access to the remainder of the storage ring, a third internal gate (gate "C") was installed to form an interlocked area surrounding the cavities. The storage ring sector 2 entrance gate access this area and, along with two interlocked concrete doors, emergency crash-off switches, internal gates "B" and "C", and other devices, form a sub-chain allowing RF testing. As can be seen, internal gate "B" functions in two chains; the linac chain because of the storage ring area between gates "A" and "B" and also the storage ring RF test chain because of the area between internal gates "B" and "C". The interlock devices for the area between internal gates "B" and "C" are summed at the storage ring sector 2 entrance gate safety racks and becomes an input for the main storage ring chain at the storage ring sector 6 entrance racks.

c) The third zone of the storage ring consists of sectors 4 through 9 and is bounded by internal gates "A" and "C". This area is normally accessed via an entrance gate at sector 6 where safety racks bring together interlocked devices within this zone as well as the two other zones discussed above. Additional inputs from the storage ring RF system (indicating it is in an operate mode as opposed to test) and an interlocked utility tunnel transiting under the storage ring and linac appear at this location to form the main storage ring chain. The utility tunnel interlocks are also shared by the linac chain discussed earlier.

The third main ALS interlock chain is the storage ring fill/stored beam chain. It has two functions. In normal, decay mode it will inhibit filling of the storage ring if the beamline safety shutters are not inserted and it turns off the storage ring RF if a beamline hutch interlock is violated. Beamline interlocks for each sector are summed at that sector and then all sectors are brought together. In order to fill the storage ring, a global fill request is sent to all beamlines to close all beamline safety shutters. This request is one input to an interlock controlling the booster-to-storage ring beam transport line bending magnets B1 and B2. When all safety shutters are closed the interlock is then complete to allow operation of the B1 and B2 magnets. Should a safety shutter open during a fill procedure, the two magnets are disabled. After the storage ring has been filled the, global fill request is removed. This relinquishes control of the safety shutters to the beamline operating stations and reasserts the inhibit of operation for the B1 and B2 bend magnets. This prevents accidental beam transport from the booster during tune-up while the storage ring is in a stored beam mode and the position of beamline safety shutters is unknown. Active radiation monitors outside the storage ring shielding also control these two magnets and the storage ring RF. Should radiation outside the shielding be detected above the trip level, the B1 and B2 magnet power supplies and storage ring RF are turned off.

Normal access to an interlocked beamline hutch is via a request to a programmable logic controller (PLC). The PLC cycles certain machine protection equipment and outputs a command to close the beamline safety shutter. Redundant micro switches sense the shutter position and if the shutter is inserted, the hutch door may be opened. To reopen the shutter, the following must occur in order: (1) the hutch search is initiated and the ‘search confirm’ push button switch inside the hutch must be pushed; (2) the hutch door is closed, and redundant door switches must sense that the door is closed; (3) the “lock door” push button on the outside of the hutch is pushed; and (4) after a delay with lights and klaxon inside the hutch, then the ‘hutch secure’ button must be pushed. After this, the interlock will release allowing the PLC system to open the shutter. Hutchless beamlines are identical except for the search requirement. The beamline control panel also allows the ALS floor operators the capability of locking out any beamline not meeting ALS standards.

3.4.2.5 Top-Off

A special issue is the prevention of electron bunches travelling far enough down the beamlines during open shutter injection (Top-Off mode) to cause significant radiation doses outside of the accelerator shield walls. A methodology was developed to identify possible magnet failures that could plausibly cause such a mis-steering [Donahue *et al*., 2008]. To prevent these from occurring, a specific set of conditions are imposed through a set of interlocks in the following systems:

- Energy Match
- Lattice Match
- Storage Ring Beam Current
- Beamline Radiation Monitor

Essentially, the energy match interlock enforces the condition that the stored beam and the injected beam are well matched and within certain tolerances. The stored beam current monitor enforces the base condition of a stable stored beam, and the lattice match interlock enforces nominal values in storage ring magnet parameters. A fault in any of these will inhibit the beam injection system, but not necessarily close the personal safety shutters. Essentially, the operational mode will revert back to decay mode from Top-Off.

The radiation monitor interlocks are designed to detect dose due to scatter upstream from the safe point calculated in the tracking studies. Both a fast and a slow trip point are enforced. A trip in this interlock system also closes the PSS for that beamline monitor.

A detailed engineering specification for this system is found in *Top-Off Mode Beam Interlock System Requirements and Design* (ALS 2008b).

3.5 DESCRIPTION OF ORGANIZATION

3.5.1 ALS Organization

In over 14 years of operation, the scientific output and capabilities of the ALS have grown dramatically. The organization of the ALS has expanded and evolved alongside that growth. The following paragraphs describe the present position of the ALS facility within the LBNL structure and the operational structure of the ALS organization.

The LBNL organization (see Figure 3-23) vests primary responsibility for all activities in the Laboratory Director.

Though the ALS falls under the Physical Sciences Directorate, the ALS Division Director reports directly to the LBNL Laboratory Director.

In the ALS organization, full responsibility for operation of the facility and development of the scientific program resides with the ALS Division Director (see Figure 3-24). Duties of the Division Director include, evaluating the need for an applying appropriate Quality Assurance policies to all ALS activities, establishing and maintaining an active environment, safety, and health program, setting overall goals for the facility, authorizing new programmatic and major R&D activities, securing and assigning resources within the ALS organization, and development of the scientific program. As the Director of an LBNL Division, the ALS Division Director has direct access to the LBNL management by such means as participation in meetings of the Division Directors. An overview of the significant parts of the organization follows:

The Operations and Accelerator Development organization operates the accelerator and is responsible for providing high quality X-rays to the beamlines.

The Engineering groups provide professional support to the accelerator and beamline programs including magnetics, RF, electrical, mechanical engineering as well as technical support in areas such as electronics maintenance and installation, and mechanical technology.

The User Services Group initiates and implements procedures for users (including proposals and user EH&S) including proposal reviews, safety reviews and authorization of user experiments, and facility access.

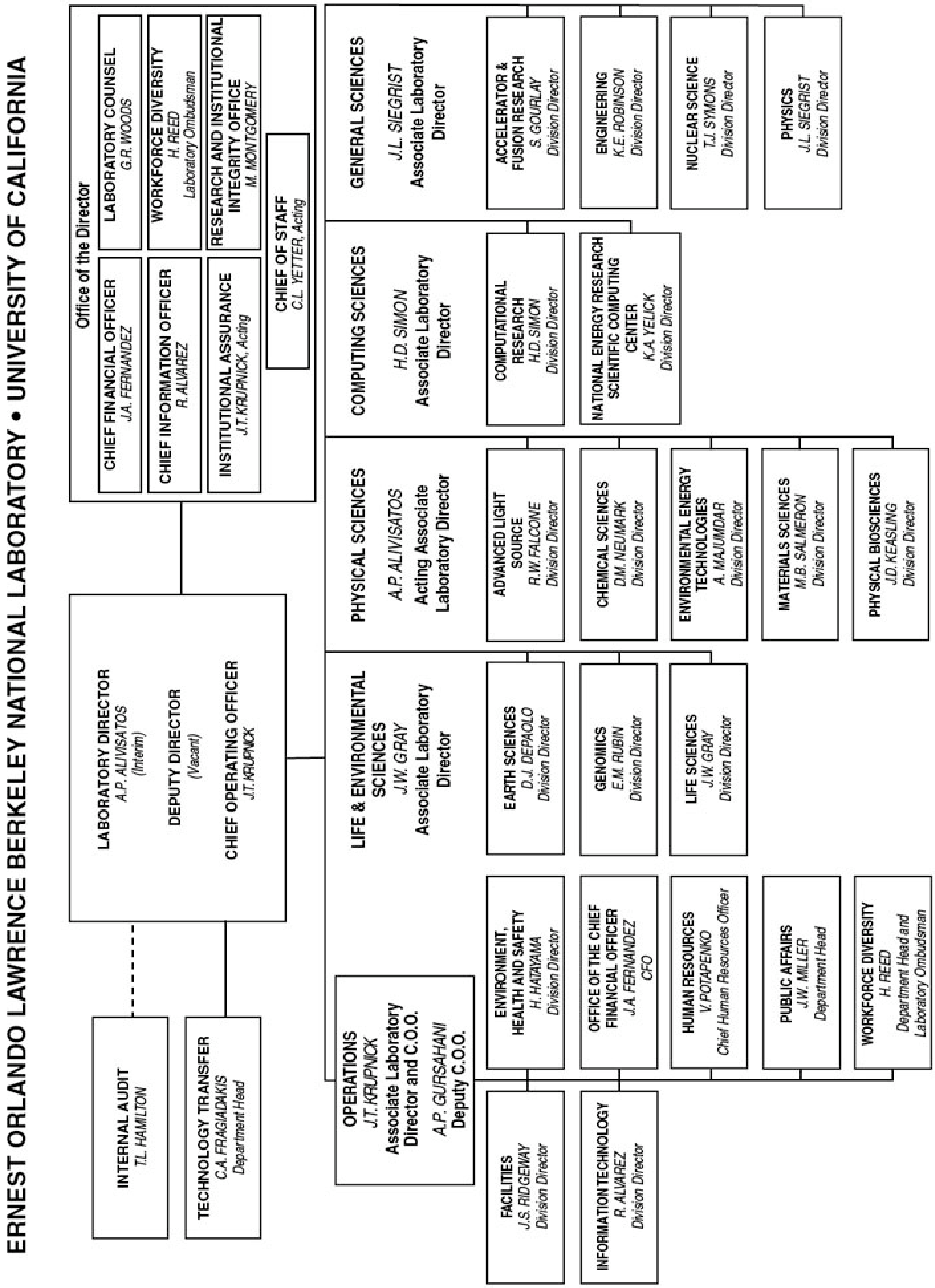

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Figure 3-23. Berkeley Lab organization chart

The ES&H Program provides overall management of the safety program at the ALS and develops facility-specific hazard control programs to meet both the institutional and regulatory requirements as well as the operational needs of the user facility. It also provides on-going assistance to all staff and supervisors through technical evaluations and monitoring.

The Experimental Systems Group (ESG) and Scientific Support Group (SSG) provide scientific and technical support to ALS users for carrying out their experiments, provides access to state-of-the-art data analysis tools for interpretation of experimental data, and develop novel and/or better experimental equipment and beamlines.

There are three primary ALS advisory committees:

- The Science Policy Board
- The Scientific Advisory Committee
- The User Executive Committee

Each of these committees provides advisory support to ALS and LBL management to assure that the scientific mission and the user's needs are being met.

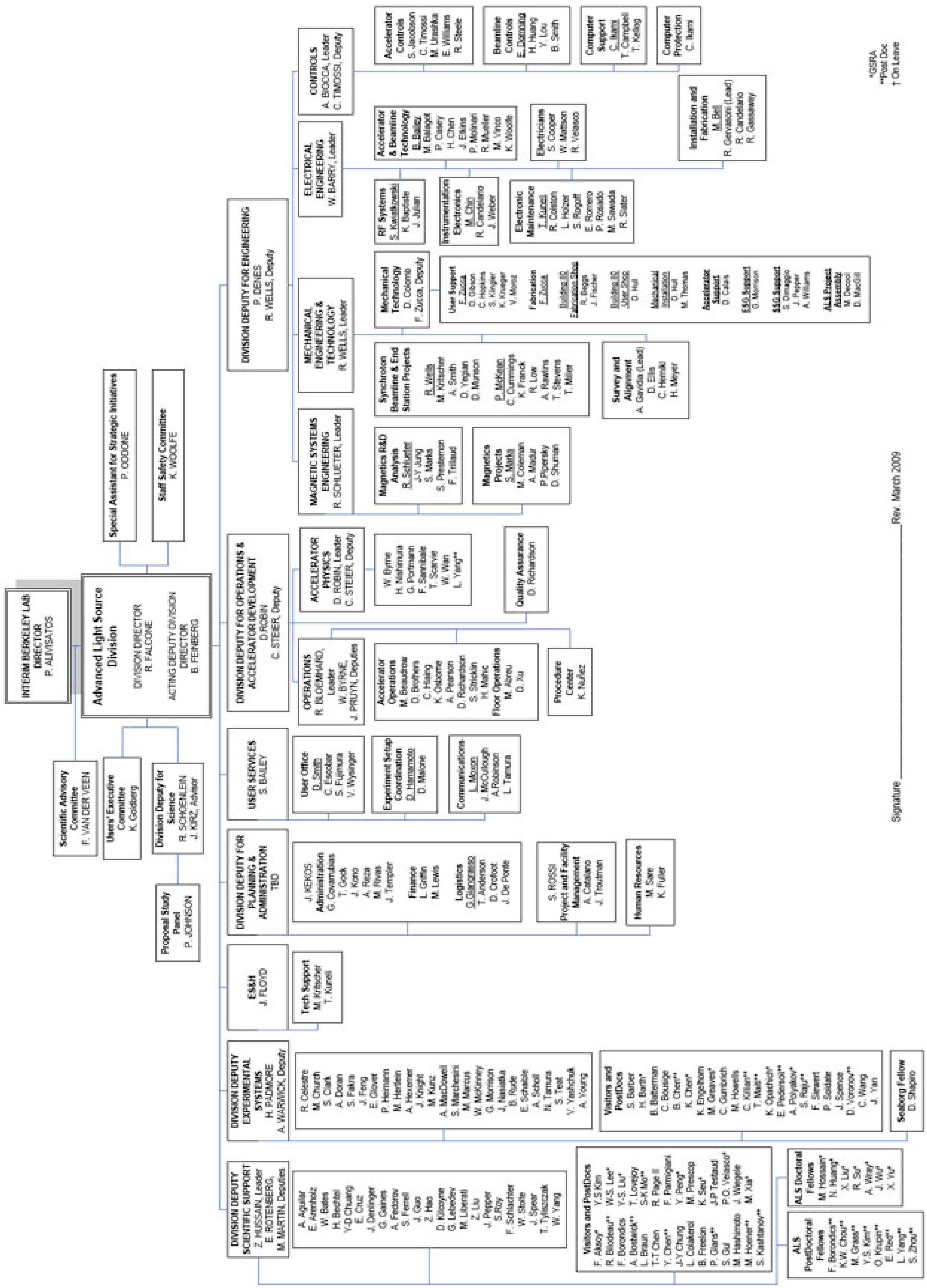

Figure 3-24. Advanced Light Source organizational chart

3.5.2 EH&S Organization

LBNL EH&S

The Laboratory Director is responsible for ensuring that LBNL's health, safety, emergency-preparedness policies are carried out. The Director has delegated the responsibility and authority necessary to implement the health, safety, and emergency-preparedness policies of the Laboratory to appropriate members of the Laboratory management and staff. In particular, the Chief Operating Officer (COO) has been delegated the authority to develop and administer the Laboratory's Health and Safety Program. The Director of the Environment, Health, and Safety Division (EHS) reports to the COO. The primary functions of the EHS Division are to ensure that LBNL's scientific programs are carried out in compliance with the applicable orders of the DOE and with the regulations of other agencies having jurisdiction; to provide professional support in various disciplines of the EHS Division to the Laboratory's scientific programs; to assist in the development of health and safety regulations; and to provide liaison with local, state, and federal agencies and with various organizations in the University of California in the field of Environment, Health, and Safety.

Formal responsibility for designing and implementing the Laboratory's radiation safety programs resides with the Radiological Control Manager, RCM who reports to the EHS Division Director. These responsibilities include the Radiation Protection Program (RPP) as required by 10 CFR 835, and the Laboratory's implementation of accelerator safety as required by DOE Order 420.2b. The RCM has designed and implemented an internal radiological work authorization (RWA) program that implements and coordinates all of these programs. All radiological use, including operation of accelerators, is covered by this RWA program.

ALS ES&H Organization

The ALS Division Director has overall EH&S responsibility for the facility and its operations. The Director has established an ALS Integrated Safety Management (ISM) Plan which states that the Advanced Light Source basic EH&S policy is to ensure that all activities are planned and performed in a manner which ensures that every reasonable precaution is taken to protect the health and safety of employees and the public, and to prevent damage to property and the environment. Consistent with the principles of integrated safety management, the ALS holds line managers accountable for safety performance.

The primary source of EH&S expertise within the ALS is the ES&H Program, whose primary responsibility is to assure that all work performed at the ALS is consistent with institutional and regulatory requirements while meeting the operational needs of the facility. The ES&H program manager reports directly to the ALS Division Director. It is the primary conduit for coordination with the LBNL Environment, Health, and Safety Division.

As described in Section 3.5.1, the ES&H Program provides technical input, evaluations, and oversight as needed to support ALS activities. Much of this involves coordinating internal and external expertise, and the overall ALS safety organization consists of staff from all parts of the ALS organization as well as support staff from the LBNL EH&S Division.

Among the functions of the ES&H Program are: audits of the facility; developing hazard communications, chemical training programs, and ES&H training programs for users, conducting inspection and work-place review activities related to both radiological and non-radiological health protection, EH&S training of ALS operating staff and users, developing facility emergency plans, and administering programs for development of required Documents (AHDs and other formal authorizations) [formerly Operational Safety Procedures (OSP's)]. In addition, the ES&H Program Manager participates in design reviews to verify that EH&S considerations have been adequately addressed and included in the final design of all ALS components and systems.

An important component of the safety program is User safety. This program is coordinated between the EH&S Program, the User Services Group and the individual Beamline Scientists. User Services is responsible for proposal review procedures and pre-experiment coordination with the users. Experiment coordination consists of determining the hazards and proper controls needed for each experiment before the users arrive. This process is encompassed in Experiment Safety Sheets (ESS). Once experiments are reviewed and approved, on-going support and oversight of the work is performed by the beamline scientific staff in SSG and ESG.

SECTION 4. HAZARD ANALYSIS

The ALS safety analysis was prepared in accordance with the guidance provided in DOE Order 5481.1B, Safety Analysis and Review System [DOE, 1986a] and in DOE Order 420.2B Safety of Accelerator Facilities, including attachments. The Implementation Guide (DOE G420.2-1) for the Accelerator Safety Order, DOE O420.2B, provides a reference for conducting safety analyses, which is DOE O5480.25, Guidance for an Accelerator Facility Safety Program [1993]. This Order provides guidance for rating the consequences and probability of each hazard and assigning levels to each, and then the overall risk associated with each specific hazard, and then for the facility as a whole, is determined using a risk matrix. Figure 4-1 provides a general overview of the safety analysis.

4.1 HAZARD ANALYSIS METHODOLOGY

This section identifies the facility hazards and describes the evaluation methodology and the results of the analysis. The purpose of this information is to present a comprehensive evaluation of potential process-related, natural phenomena, and external hazards. Hazard analysis includes both hazard identification and hazard evaluation. The hazard identification and evaluation provide a thorough, predominantly qualitative evaluation of the spectrum of risks to the public, workers, and the environment.

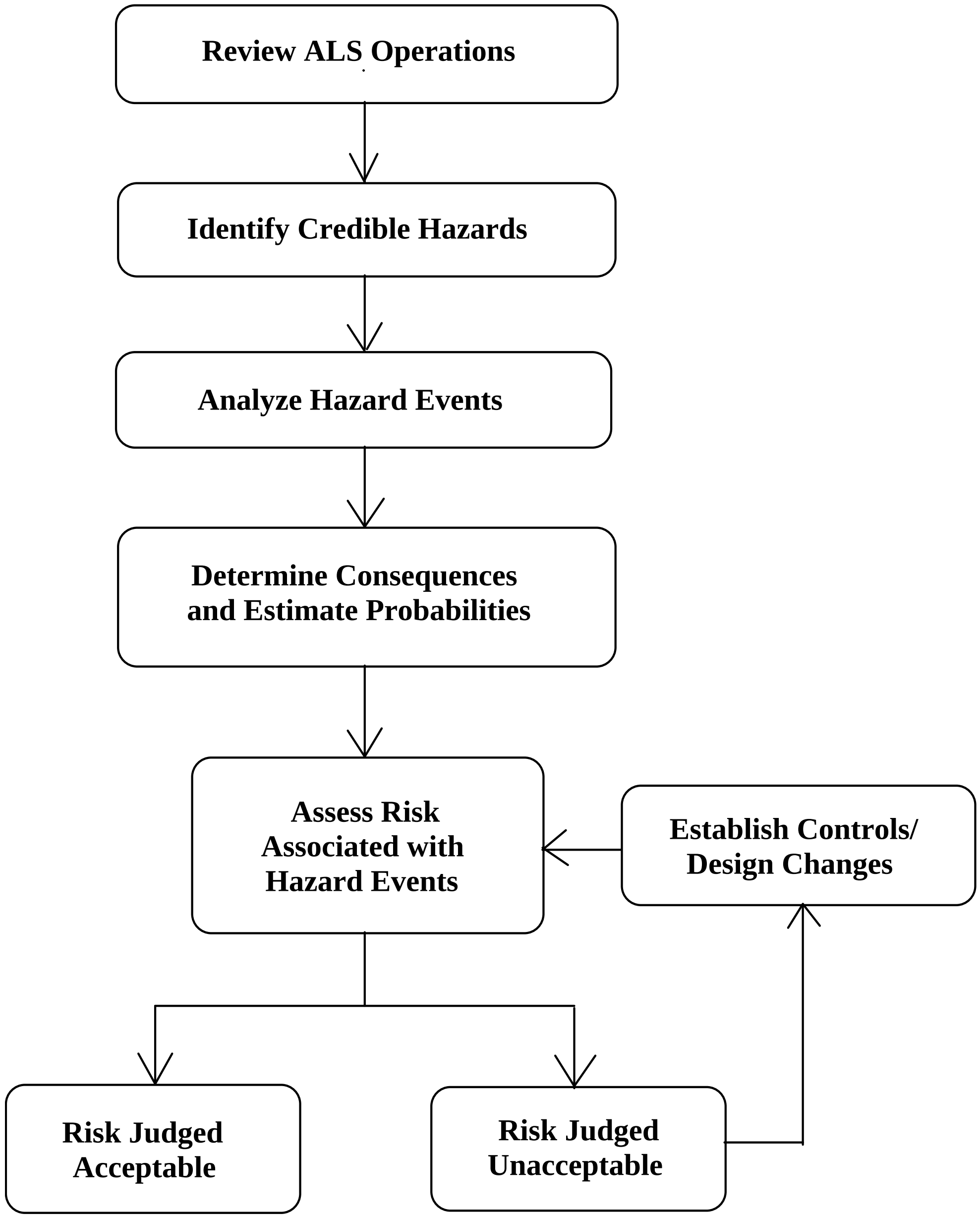

Figure 4-1. ALS Safety Analysis Methodology.

4.1.1 Hazard Identification Methodology

The hazard identification process began with a review of the Advanced Light Source (ALS) facility operations and the existing facility safety documentation. A screening for the potential hazards associated with the ALS facility was performed using a checklist adopted from Appendix A "Potential Hazards" of ANL ES&H Manual Section 21.2 "Experiment Safety Review". A hazard was considered to be anything having the potential to cause harm to workers, property, the public, or the environment—including both energy sources and hazardous materials in the facility. These hazards and their locations were identified through walkthroughs, a review of existing documents and past occurrences, and in consultation with facility personnel and a team of ES&H professionals. External hazards and natural phenomena hazards were also identified.

4.1.2 Hazard Evaluation Methodology

This section summarizes the basic approach used for event development and for generating the largely qualitative consequence and probability estimates obtained for the hazard evaluation. It also contains the criteria used for ranking accidents by probability and consequence for workers and the public.

The hazard evaluation can be separated into two distinct parts:

1. Process hazard analysis, which addresses the hazards and risks associated with ongoing operations in the facility.
2. Natural phenomena and external events.

The process hazard analysis used a modified what-if methodology as a systematic approach for updating and validating the process hazards and for assessing qualitatively, or semi-quantitatively, the risk(s) of those hazards. The modified *what-if* approach was used to answer the following questions:

- What can happen?
- How likely is it (frequency estimate)?
- What is the damage (consequence estimate)?

The modified what-if hazard analysis is a qualitative, formal, and systematic method for assessing the set of possible hazardous events for a given facility. Based on the hazards identified in the facility in terms of hazardous materials and potential energy sources, facility operations were examined to identify potential scenarios wherein a hazardous event might occur. The events are identified in Table 4-5.

Common data are provided for each event identified in Table 4-5. The “Event” field provides the specific alphanumeric label. The “Hazard Summary” field identifies the type of hazard (thermal, radiation, etc.) and provides a brief description of the event and any specific material at risk that may be affected. The “Cause” field identifies the general event initiator. The “Preventive Features” field lists those engineered and administrative features in place to prevent the hazardous event from occurring. The “Mitigative Features” field describes those engineered and administrative features in place to reduce the consequence of the hazardous event. The “Consequence” field provides a qualitative description of the consequence(s) associated with the hazardous event, both mitigated and unmitigated. The “Frequency” field qualitatively gives the relative probability of the hazardous event occurring. The “Risk” field qualitatively assigns a risk category to the unmitigated and mitigated event. The “Comment” field is provided to assist readers in understanding any key assumptions or bases of the evaluation.

All engineered and administrative features that could either prevent or mitigate the hazardous event identified were included for completeness. However, it was not intended for all such features to be interpreted as Accelerator Safety Envelope (ASE) requirements. Only controls credited to reduce unmitigated “High” or “Moderate” risks are typically included in the ASE.

The probability of an event occurring was categorized based on the likelihoods given in Table 4-1. Probability levels were assigned on the basis of previous assessments, occurrence reports, or engineering judgment.

Table 4-1. Probability Rating Levels

Category	Symbol	Description	Estimated Range of Probability of Accident per Year
High	I	Event is likely to occur several times during the facility or operation lifetime.	$>10^{-1}$
Medium	II	Event anticipated to occur once or twice during the facilities lifetime (such as 100-yr flood)	10^{-1} to 10^{-2}
Low	III	Event should not occur during the facility's lifetime (such as a design basis accident)	10^{-2} to 10^{-4}
Extremely Low	IV	Probability of event is incredible	$<10^{-4}$

Worker and public safety and health consequences were assigned based on the ratings in Table 4-2.

Table 4-2. Consequences of Occurrence Matrix

Consequence Level	Consequence Description	
	Public	***Worker***
A	**Considerable impact – potentential for immediate or long-term health effects** Radioactive material dispersal (with potential for doses > 25 rem) Tosic material dispersal (>ERPG-2)	**Potential for immediate and severe health effects, significant long-term health effects or disability, or potential for loss of life.** Very large radioactive material dispersal (qualitative dose estimate > 100 rem) Tosic material dispersal (>ERPG-3 or IDLH)
B	**Limited impact on people or the environment- Potential for precautionary evacuation** Radioactive material dispersal (with potential for doses between 1 and 25 rem) Toxic material dispersal (between ERPG-1 and ERPG-2)	**Serious injury or significant radiation or chemical exposure** Significant radioactive material dispersal (between 25 and 100 rem) Toxic material dispersal (>ERPG-2)
C	**No significant impact** Radioactive material dispersal (with doses from 0.1 to 1 rem) Tosic material dispersal (< ERPG-1)	**Minor injuries with no disability or work restrictions** Low energy and/or small quantity radioactive release yielding minor dispersion (<25 rem) Toxic material dispersal (<ERPG-2
D	**Negligible impact**	**Negligible impact**

The levels for worker and public consequences were assigned based on the estimated magnitude of exposure or on the estimated extent of the injury. The basis for the assignment of the consequence levels was the current exposure guidelines and accepted risks. Use of an unmitigated approach to assign consequences ensures that events with the potential for significant public exposures receive a high priority during the accident selection process.

A preventive feature is a physical or administrative feature that, if it functions as intended, will not allow the hazardous event to develop. A mitigative feature is a physical or administrative feature that, if it functions as intended, will act to reduce the consequences of the hazardous event once it has occurred.

The matrix used to establish the overall risk to workers and the public is shown in Table 4-3. These risk rankings are used to determine which hazard events are selected for the detailed accident analysis to verify the adequacy of the selected features and controls for protecting workers and the public.

Table 4-3. Hazard Analysis Risk Matrix*

	FREQUENCY CATEGORY			
CONSEQUENCE CATEGORY	**I**	**II**	**III**	**IV**
A death/loss of facility	**High**	**High**	Moderate	Low
B severe injury	**High**	Moderate	Low	Negligible
C minor injury	Low	Low	Negligible	Negligible
D negligible	Negligible	Negligible	Negligible	Negligible

* Risk assignment is relative, not absolute, to allow ranking.

The hazard evaluation identified the spectrum of hazardous events that might occur in the facility. A postulated event may have a range of potential consequences that may affect workers or the public. A set of identified accidents based on the results of the hazard evaluation is analyzed further in Section 4.3 Accident Analysis.

4.2 HAZARD ANALYSIS RESULTS

The following sections provide the results of the hazard identification and hazard evaluation. The hazard evaluation section includes a discussion of the evaluation of normal, abnormal and accident conditions.

4.2.1 Hazard Identification Results

A comprehensive list of hazards in the facility is provided in Table 4-4 "Potential Hazards Checklist". These hazards and their locations were identified through the use of checklists, walkthroughs, a review of existing documents and past occurrences, and in consultation with facility personnel and a team of ES&H professionals. A "Y" in the "Present" column indicates that the potential hazard is present, and an “N” indicates that it is not.

The majority of the hazards at ALS facility can be characterized as standard industrial hazards. DOE Guide 420.2-1, *Accelerator Facility Safety Implementation Guide for DOE) 420.2B, SAFETY OF ACCELERATOR FACILITIES*, states:

> “Standard industrial hazards normally do not need to be addressed in the SAD. Standard industrial hazards are those that are routinely encountered and accepted in general industry and for which national consensus codes and/or standards exist to guide safe design and operation. However, standard industrial hazards should be evaluated for the potential to serve as initiators for accidents related to specific accelerator processes.”

A “Y” in the “Standard Industrial Hazard” column indicates that the potential hazard is a standard industrial hazard, and an “N” indicates that it is not.

Table 4.4. Potential Hazards Checklist

(adopted from Appendix A "Potential Hazards" of ANL ES&H Manual Section 21.2 "Experiment Safety Review")

POTENTIAL HAZARD	**Present?**	**Standard Industrial Hazard?**
Radiation and Electromagnetic Fields		
Ionizing Radiation		
Prompt radiation from the electron beam (Neutron and Bremsstrahlung)	Y	
Synchrotron radiation	Y	
Ionizing radiation from radioisotopes	Y	
Subatomic	N	
Nonionizing Radiation		
Laser	Y	Y
Visible Light	Y	Y
Ultraviolet	Y	Y
Infrared	Y	Y
Microwave	Y	Y
Radiofrequency	Y	Y
Electric Fields	Y	Y
Magnetic Fields	Y	Y
Chemicals and/or Materials		
Health and Injury Hazards		
Carcinogens	Y	Y
Mutagens	Y	Y
Teratogens	Y	Y
Toxins	Y	Y
Corrosives	Y	Y
Irritants, Allergens, and/or Sensitizers	Y	Y
Volatile Solvents	Y	Y
Combustion and Injury Hazards		
Flammable Liquids and/or Solvents	Y	Y
Metallic Combustibles	Y	Y
Flammable Gases	Y	Y
Compressed Oxygen	Y	Y
Open Flame or Sparks	Y	Y
Combustible Materials	Y	Y
Explosives	N	
Flammable Suspended Dust Particles	N	
Pyrophoric Chemicals	Y	Y
Respiratory or Contact Injury Hazards		
Cryogenics	Y	Y
Thermal (High or Low)	Y	Y
Dust, Particulates, and Fibers	Y	Y
Asbestos	Y	
Explosives	N	

POTENTIAL HAZARD	Present?	Standard Industrial Hazard?
Reactive Chemicals	Y	Y
Compressed Gases	Y	Y
Pressure and/or Vacuum Systems	Y	Y
Steam	N	
Asphyxiation	Y	Y
Stored Energy Not Elsewhere Addressed		
Hydraulic Energy	N	
Kinetic Energy	N	
Mechanical Energy	Y	Y
Potential Energy	N	
Other	N	
Biohazards		
Virus	Y	Y
Bacteria	Y	Y
Human Tissues and/or Body Fluids	Y	Y
Animals and Animal Tissue	Y	Y
Electrical		
High Voltage Devices	Y	Y
Storage Devices	Y	Y
Static Charge	N	
Grounding	Y	Y
Exposed Conductors	Y	Y
Mechanical		
Lifting Devices	Y	Y
Low Friction Surfaces	N	
Load-Bearing Components	N	
Vibration	N	
Sharp Points or Edges	N	
Moving Parts	Y	Y
Pinch Points	N	
Ladders, Scaffolds, and/or Platforms	Y	Y
Work Environment		
Activities at Known or Suspected Hazardous Waste Sites	N	
Use of Self-Contained Breathing Apparatus	N	
Temperature or Other Climatic Extremes	N	
Noise	Y	Y
Confined Spaces	Y	Y
Natural Phenomena		
Earthquake	Y	
Wildland Fire	Y	
Severe Weather	Y	

Potential Hazards at the ALS

Radiation Fields

Ionizing-radiation hazards at the ALS are due to loss of electrons at various stages of the beam acceleration and storage process and to the synchrotron radiation emerging from the insertion devices and bend magnets in the storage ring. Ionizing radiation is also produced by accelerator-related equipment, such as the klystrons that generate rf power. Credible hazards fall into two primary categories. The first category is exposure to ionizing radiation resulting from operation of the machine. Exposures can result from normal operation of the accelerators or from accidental loss of beam. The second category is exposure of personnel inside the accelerator shielding or exclusion areas.

For synchrotron-radiation facilities, bremsstrahlung (photons) and neutrons are the dominant ionizing radiation. Electrons lost from the accelerator beam generate bremsstrahlung when colliding with residual gas molecules in the accelerator vacuum chambers, with the chamber walls, or with other objects. Neutrons are generated, primarily by the giant photo-nuclear resonance, when the bremsstrahlung is absorbed by shielding.

Different levels of photon and neutron radiation are produced during different stages of operation. For example, in the case of the storage ring, the first stage of interest is the injection cycle. The efficiency of the injection process determines the average level of radiation. However, mis-steering the beam into the storage-ring or booster-to-storage ring transfer line will produce the most significant levels of radiation, so that special consideration must be applied in designing the shielding for the injection region. The next stage of operation after injection is stored beam in the storage ring.

Under normal conditions when beam is gradually lost over several hours, one would be concerned with the radiation produced by the interaction of electrons with atoms distributed in the storage-ring vacuum chamber (gas bremsstrahlung) and the radiation produced by the collision of electrons that are slowly lost from stable orbit with the vacuum chamber. Under accident conditions, one must evaluate the radiation produced when the entire electron beam is lost at a single point in the storage ring. The final stage of operation is dumping the electron beam when it has decayed and needs to be replenished. Similar scenarios exist for the booster synchrotron and the linear accelerator.

In general, shielding consists of concrete supplemented with lead and polyethylene. As a hydrogenous material, concrete is an effective material for neutron shielding. Polyethylene, another hydrogenous material, is used to provide additional neutron shielding. Concrete also protects against bremsstrahlung, but the required thickness is so large that it is not always practical to rely exclusively on concrete. Lead, which is a more effective bremsstrahlung shield material than concrete, is therefore used to provide additional protection.

The bremsstrahlung dose equivalent far exceeds the average neutron dose equivalent and will dominate the shielding [Swanson, 1985]. Hence, it is very probable that an adequate shield for bremsstrahlung would be more than adequate for neutrons, if concrete were used. However, if bremsstrahlung were shielded primarily by non-hydrogenous materials, such as lead or iron, the neutrons may not be adequately attenuated. The combination of concrete and lead is optimized to provide maximum shielding. Additional lead and polyethylene are used for local shielding in critical locations where space or geometrical constraints are an important consideration.

<u>Other Radiation Sources</u>

ALS uses a variety of sealed and unsealed radioactive materials on an infrequent basis. Examples of some of the sealed material uses are Am-241 to verify lead shielding, Fe-55 as a low energy photon source for detector development and Po-210 for static eliminators. Unsealed materials such as actinides are of interest to ALS users and are brought to beamlines for a variety of experiments. These uses are all evaluated and controlled through standard LBNL radiation protection programs such as inventory control, labeling, surveys, contamination control, dosimetry, training, etc. which are a part of the institutional Radiation Protection Program (RPP) that implements 10 CFR 835.

<u>Activated Materials</u>

Another potential source of radiation comes from activation of non-radiological materials. The beams and energies achievable from the ALS may cause low levels of activation of beam components, beam stops and beamline components along the path of the beam. All materials with a potential to be activated are surveyed for release before they are removed from the accelerator tunnels. Only a very small fraction has had long-lived activation components and these have generally been in the few to tens of pCi/gram range.

Non-ionizing Radiation

The Rf systems for the sub-harmonic bunchers (24kW peak) operate at frequencies of 124.91 MHz and 499.65 MHz and at an average power of <10W. The high power Rf is contained in coax cable and buncher cavities. The RF system for the Linac uses two high-power (25 MW peak) klystrons operating at a frequency of 2997.9 MHz and an average power level of < 250W each. The high-power RF is contained within the interlocked vacuum waveguide or accelerator cavities and poses no health hazard since high power RF operation is inhibited without high vacuum. The RF system for the Booster synchrotron (15 kW peak) operates at a frequency of 499.65 MHz and an average power of 10.9 kW. The high power RF is contained in the transmission system and accelerating cavity. The RF power amplifiers and transmission line systems were manufactured to a specification [ANSI] which required that RF leakage level, for near field exposure from the source, from these units be below 1 mW/cm^2, 5 mW/cm^2 and 1.67 mW/cm^2 for 124.91 MHZ, 2997.9 MHz and 499.65 MHZ respectively. Leakage measurements are made by an EH&S radiation safety technician or by a member from the RF Group after every transmission system modification or disassemble/reassemble process to ensure continued conformance with the specification.

Chemical Hazards

ALS operations do not involve complex chemical processing activities. Quantities of hazardous chemicals can therefore be characterized as typical lab scale quantities. Quantities and types of work allowed on the accelerator floor are regulated through the Experiment Safety Sheet process. The use and storage of hazardous materials are controlled through the LBNL Chemical Safety and Hygiene Plan and the total quantities are limited according to the 1988 Uniform Fire Code. A subset of this inventory is toxic chemicals in gaseous form. These are limited to small quantities, most of which are in small lecture bottles.

Standard Industrial Hazards

Standard industrial hazards include noise, moving machinery, high pressure gas cylinders, forklifts, ladders, scaffolding and platforms, vacuum systems subject to overpressurization and subsequent fragmentation, normal industrial levels of combustible loading, and numerous electrical distribution systems. These hazards are of interest as fire initiators, sources of significant mechanical impact, and as means to interrupt operations in an unplanned manner.

4.2.2 Hazard Evaluation Results

The hazards identified in the previous section have been developed into numerous hazardous events that could result in the release of unwanted energy or hazardous material (toxic, corrosive, radioactive). These events are presented in Table 4-5. Some events present no risk of radioactive or chemical exposure to workers or the public, but are included in the table for completeness.

Identified for each hazardous event in Table 4-5 are the causes, engineered features for preventing or mitigating unwanted effects, and administrative features for preventing or mitigating the event. A preventive feature is a physical feature that, if it functions as intended, will not allow the hazardous event to develop. A mitigative feature is a physical feature that, if it functions as intended, will act to reduce the consequences of the hazardous event once it has occurred. Administrative features include preventive and mitigative features that involve human intervention. As previously discussed, engineered and administrative features include for completeness all features in the facility that could prevent or mitigate the hazardous event. It was not intended for all such features to be interpreted as ASE requirements. However, features credited with reducing the frequency or consequence of "High" and "Moderate" risk events are listed in bold type in Table 4-5. An estimate of the probability, the potential consequences, and the risk to workers and the public is assigned to each event in Table 4-1 using the methodology described in Section 4.1.2, Hazard Evaluation Methodology.

Many of the hazards associated with ALS operations are of the type and magnitude considered as standard industrial hazards (e.g., exposure to electrical shock, falls from platforms and scaffolding, improper operation of rotating machinery). Such hazards are considered only as potential initiators to an accelerator specific hazard in Table 4-5 but were not evaluated as potential hazard scenarios themselves.

Certain assumptions regarding a facility and its operations, called initial conditions, are included in the unmitigated phase of the hazard evaluation. Initial conditions are generally intended to facilitate scenario definition and include items such as inventory information and capabilities of passive features (i.e., no mechanical or human involvement). Any initial condition assumed must be assessed for inclusion in the Accelerator Safety Envelope (ASE).

Two initial conditions are defined for the hazard analysis. All are preserved in the ASE. These conditions are:

1. Beam Design – The operational parameters of linac power (< 0.85 W), booster power (< 8.25 W), and, for the storage ring, stored beam energy (< 1000 J), electron energy (1.96 GeV), and current (800 mA) are controlled to assure that accelerator conditions do not exceed the design basis of the shielding.
2. Shielding – Permanent shielding is sufficient to reduce the radiation at the site boundary to well below the DOE limit of 100 mrem/year for members of the public and to reduce the radiation within the generally occupied areas of the building and surround environs to meet the targets of the ALS shielding policy (which are set well below the DOE occupational limits of 5 rem/year).

Table 4.5. Hazards Characterization for the ALS Facility.

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
EVENT 1: Exposure to Radiation from Operation (i.e., neutron, gamma, beta, X-ray, etc.)								
1a.	**Radiant** Personnel exposure to radiation produced by electron beams	Operation	<u>**Engineered:**</u> **Beam Design (Initial Condition - IC), Shielding (IC)** <u>**Administrative:**</u> Procedures, Training	<u>**Engineered:**</u> None <u>**Administrative:**</u> Radiation Protection Program	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* I *Mit:* I	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit*: Neg	This event establishes the baseline condition for safe operation of the accelerator.
Accelerator								
1b.	**Radiant** Personnel exposure to neutron & bremsstrahlung radiation produced by electron beams	Human Error Accelerator (LINAC, Booster, Storage Ring) is occupied when beam is generated.	<u>**Engineered:**</u> **Radiation Safety System (RSS)** <u>**Administrative:**</u> **Search procedure,** Training (i.e., allowed occupancy locations during operation)	<u>**Engineered:**</u> None <u>**Administrative:**</u> None	**Worker** *Unmit:* A *Mit:* A **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* IV	**Worker** *Unmit:* High *Mit:* Low **Public** *Unmit:* Neg *Mit:* Neg	The RSS works in tandem with the Search Procedure to force a systematic close-out of the accelerator tunnels. It also provides a Crash-off panel that allows the at-risk individual to preclude operation. Both of these controls reduce frequency.
1c.	**Radiant** Personnel exposure to neutron & bremsstrahlung radiation produced by electron beams	Mechanical Degradation Concrete blocks develop leak paths	<u>**Engineered:**</u> Beam Design (IC) <u>**Administrative:**</u> Shielding control procedures, Training	<u>**Engineered:**</u> Radiation monitors <u>**Administrative:**</u> Radiation surveys, accelerator start-up procedure	**Worker** *Unmit:* *C* *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Physically large nature of the accelerator shielding makes a meaningful leak path hard to develop and hard to miss.

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
1d.	**Radiant** Personnel exposure to neutron & bremsstrahlung radiation produced by electron beams	Human error Concrete blocks are not properly configured	**Engineered:** Beam Design (IC) **Administrative:** Shielding control procedures, Training	**Engineered:** Radiation monitors **Administrative:** Radiation surveys, accelerator start-up procedure	**Worker** *Unmit:* *C* *Mit:* *D* **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Physically large nature of the accelerator shielding makes a meaningful leak path hard to develop and hard to miss. Roof blocks are only ones that are moved – at 90 degrees; small resultant dose.
1e.	**Radiant** Personnel exposure to bremsstrahlung radiation produced by electron beams	Mechanical Degradation Bremsstrahlung shielding outside shield wall develop leak paths	**Engineered:** Beam Design (IC) **Administrative:** Beamline review process, Training	**Engineered:** Radiation monitors **Administrative:** Beamline review process, radiation surveys	**Worker** *Unmit:* *C* *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:*Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Stable, simple shielding that is rarely moved. Subject to formal design review and controls (BRC, shielding control, key enable checklist) Scenario: PB becomes unpacked allowing slight streaming and/or scattering. Could get mR/hr fields.
1f.	**Radiant** Personnel exposure to bremsstrahlung radiation produced by electron beams	Human error Bremsstrahlung shielding outside shield wall is not properly configured	**Engineered:** Beam Design (IC) **Administrative:** Beamline review process, Training, Maintenance	**Engineered:** Radiation monitors **Administrative:** Beamline review process, radiation surveys	**Worker** *Unmit:* *B* *Mit:* C **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Low *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Stable, simple shielding that is secured in place and labeled. Subject to formal design review and controls (BRC, shielding control, key enable checklist) Scenario: Pb not repacked properly after maintenance work. Could get fields in 5-10 R/hr range. Various redundant inspections in place to prevent, and radiation monitors to catch if missed.

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
Synchrotron								
1g.	**Radiant** Personnel exposure to synchrotron radiation from a hard X-ray beamline.	Human Error Beamline enclosure (hutch) is occupied when X-rays are generated.	**<u>Engineered:</u>** **Radiation Safety System (RSS)** **<u>Administrative:</u>** **Search Procedure,** Training	**<u>Engineered:</u>** None **<u>Administrative:</u>** None	**Worker** *Unmit:* A *Mit:* A **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* IV	**Worker** *Unmit:* High *Mit:* Low **Public** *Unmit:* Neg *Mit:* Neg	The RSS works in tandem with the Search Procedure (Hutch Access) to force a systematic close-out of the beamline hutches. It also provides a Crash-off panel that allows the at-risk individual to preclude operation. Both of these controls reduce frequency.
1h.	**Radiant** Personnel exposure to synchrotron radiation from a hard X-ray beamline.	Human error Beamline shielding not properly configured	**<u>Engineered:</u>** None **<u>Administrative:</u>** **Beamline Review process,** Training	**<u>Engineered:</u>** **Radiation monitors (part of the RSS)** **<u>Administrative:</u>** Radiation surveys, RWA	**Worker** *Unmit:* *A* *Mit:* B **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* III	**Worker** *Unmit:* High *Mit:* Low **Public** *Unmit:* Neg *Mit:* Neg	Scenario: key upstream shielding from a Superbend beamline is left off. Could get lethal doses in short periods of time. These pieces are subject to usual beamline review, shielding control, key enables, etc. plus RSSD locks, etc. Interlocked radiation monitors in place. Can have scenarios involving lower dose consequences that are more frequent (with risk = Neg.)

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
1i.	**Radiant** Personnel exposure to synchrotron radiation from a hard X-ray beamline.	Mechanical Degradation Beamline shielding develops leak paths	**<u>Engineered:</u>** None **<u>Administrative:</u>** Beamline Review process, Training	**<u>Engineered:</u>** Radiation monitors (part of the RSS) **<u>Administrative:</u>** None	**Worker** *Unmit:* *B* *Mit:* C **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Low *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Similar to 1f. Higher dose rate scenarios would involve very simple beam shielding components. Have equal probabilities and consequences. Can have scenarios involving lower dose consequences that are more frequent (with risk = Neg.)
EVENT 2: Accelerator Mis-operation								
2a	Loss of Power	Mechanical Failure, Human Error	**<u>Engineered:</u>** Dedicated electrical Substation, fail-safe design **<u>Administrative:</u>** Operations directed from control room, Maintenance, Training	**<u>Engineered:</u>** Standby power generator **<u>Administrative:</u>** Recovery directed from control room	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* *D* *Mit:* *D*	*Unmit:* I *Mit:* I	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Loss of power causes beam dump – radiation losses contained within accelerator shielding
2b	Forced to abandon operations	Local threat such as fire, natural phenomena	**<u>Engineered:</u>** None **<u>Administrative:</u>** Operations directed from control room, Maintenance, Training	**<u>Engineered:</u>** Radiation Safety System (RSS), Control room shutdown capability, thermal overloads **<u>Administrative:</u>** Recovery directed from control room	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* I *Mit:* I	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Operation either terminates from initiator, or is terminated as part of evacuation. No significant runaway potential exists in the operation if abandoned. Failure of experiment and equipment damage are the risk, and reentry would be controlled through ALS and LBNL emergency response procedures.

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
2c.	Electron beam mis-steer downstream of safe point during Top-Off injection results in personnel exposure	Magnet failure	**Engineered:** **Top-Off Interlocks (part of RSS)** **Administrative:** **Procedure for Top-Off qualification of beamlines (part of Beamline Review process)**	**Engineered:** **Radiation monitors (part of RSS)** **Administrative:** None	**Worker** *Unmit:* A *Mit:* B **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* IV	**Worker** *Unmit:* High *Mit:* Neg. **Public** *Unmit:* Neg *Mit:* Neg	Dose rates ~100s R/pulse. Qualification procedure to determine and control possible phase space; interlocks to prevent such. Radiation monitors in event a bunch does travel past safe point.
2d.	Electron beam mis-steer upstream of safe point during Top-Off injection results in personnel exposure	Magnet failure	**Engineered:** Top-Off Interlocks (part of RSS) **Administrative:** **Procedure for Top-Off qualification of beamlines (part of Beamline Review process)**	**Engineered:** **Radiation monitors (part of RSS)** **Administrative:** None	**Worker** *Unmit:* B *Mit:* D **Public** *Unmit: D* *Mit: D*	*Unmit:* II *Mit:* II	**Worker** *Unmit:* Mod. *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Dose rates 30 mrem/pulse. Radiation monitors designed to detect and trip accelerator.
EVENT 3: Exposure to Radiation from Activated or Experimental Materials								
3a.	**Radiant** Personnel exposure to activated material	Human Error Personnel in proximity without being aware of radiation field or spread of contamination	**Engineered:** None **Administrative:** Radiological Work Authorizations, Low Activity Documents, Work planning inspections, Training	**Engineered:** Dosimetry **Administrative:** Radiation surveys	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* I *Mit:* I	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Worst case unshielded dose potential is on the order of 5 mrem/hr at 30 cm. Any contamination spread involves extremely small quantities due to the physical nature of the risk.
3b.	**Radiant** Personnel exposure to experimental RAM.	Human error in handling Exposure to direct target or contamination	**Engineered:** None **Administrative:** Training, Inventory control	**Engineered:** None **Administrative:** None	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* I *Mit:* I	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Materials are micro curie level and lower. Small-scale contamination event only. RPP maintains inventory below 0.5 of Cat. III Facility.
EVENT 4: Mechanical Impact								
4a.	**Radiant** Personnel	Mechanical Failure or Human Error	**Engineered:** None	**Engineered:** None	**Worker** *Unmit:* D	*Unmit:* I	**Worker** *Unmit:* Neg	Per DOE-HDBK-3010-94, airborne release fractions for

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
	exposure to activated material	Forklift, hoist, etc. fails or is misoperated , failed gas cylinder, equipment drop during elevated work Activated item impacted	**Administrative:** LBNL Rigging program requirements, Gas cylinders procured to ASME code Training, Maintenance	**Administrative:** Radiation surveys	*Mit:* D **Public** *Unmit:* D *Mit:* D	*Mit:* I	*Mit:* Neg. **Public** *Unmit:* Neg *Mit:* Neg	physical impact to solid material other than powders yields "no significant airborne release." This is typically interpreted as an airborne release fraction (ARF) of less than 1 x 10^{-5}. Small quantity and small ARF yield negligible consequences.
4b	**Radiant** Personnel exposure to experimental material	Same as 4a Source material impacted	**Engineered:** None **Administrative:** RPG sealed source program, LBNL Rigging program requirements, Gas cylinders procured to ASME code Training, Maintenance	**Engineered:** None **Administrative:** Radiation surveys	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* II	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Sources are microcurie to millicurie level. Small-scale contamination event only. Some sources may contain sintered or powder-like material. However, worst case ARF values would be on the order of 2 x 10^{-3}, with the more likely value ~ 1 x 10^{-4}. Given the quantities involved, this is at most a D consequence to workers.
EVENT 5: Fire								
5a.	**Radiant** Radioactive material (unsealed, research) release due to a facility fire	Fire initiated by general facility fire loading or activities (e.g.,welding, open flames) Activated material, or source affected	**Engineered:** Fire detection and suppression system. **Administrative:** Combustible loading controls, Training	**Engineered:** Concrete structure **Administrative:** Fire extinguishers, fire department response	**Worker** *Unmit:* C *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* II	**Worker** *Unmit:* Low *Mit:* Neg **Public** Unmit Neg *Mit:* Neg	A typical fire initiator or small-scale fire is unlikely to affect material. A larger fire occurs at a smaller frequency and is deemed Unlikely. HotSpot dose calculations yield small doses (0.2 rem to public).
5b.	**Radiant** Radioactive material (sealed, activated)	Fire initiated by general facility fire loading (e.g., flammable liquds and gases) or	**Engineered:** Fire detection and suppression system.	**Engineered:** Concrete structure **Administrative:**	**Worker** *Unmit:* C *Mit:* D **Public**	*Unmit:* II *Mit:* II	**Worker** *Unmit:* Low *Mit:* Neg **Public**	Only small quantities of material are involved. The ARF values will be 1 x 10^{-3} or less, thus no public consequences of note. Worker consequences could be C, but the

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
	release due to a facility fire	activities (e.g.,welding, open flames) Acitvated material, or source affected	**Administrative:** Combustible loading controls, Training	Fire extinguishers, fire department response	*Unmit:* D *Mit:* D		Unmit Neg *Mit:* Neg	size of the fire is presumed to preclude their remaining in the area until the release occurs.

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
EVENT 6: Natural Phenomena Hazards								
6a.	**Radiant** Seismic event impacts facility and releases radioactive material	Seismic event Partial/total building collapse	**Engineered:** Building construction **Administrative:** None	**Engineered:** Concrete structure **Administrative:** Emergency Response, Training	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* II *Mit:* II	**Worker** *Unmit:* Neg *Mit:* Neg **Public** Unmit Neg *Mit:* Neg	As noted for Event 5, the materials being handled are not susceptible to significant release under impact. The likely release in a collapse would be even less due to deposition in the rubble field.
6b.	**Radiant** Seismic event results in degradation of concrete shielding	Seismic event Human error	**Engineered:** Beam Design (IC) **Administrative:** Shielding control procedures, Training	**Engineered:** Radiation monitors **Administrative:** Radiation surveys, accelerator start-up procedure	**Worker** *Unmit:* *C* *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Physically large nature of the accelerator shielding makes a meaningful leak path hard to develop and hard to miss. (*Similar analysis to event 1c*)
6c.	**Radiant** Seismic event results in degradation of bremsstrahlung shielding	Seismic event Human error	**Engineered:** Beam Design (IC) **Administrative:** Beamline review process, Training, Maintenance	**Engineered:** Radiation monitors **Administrative:** Beamline review process, radiation surveys	**Worker** *Unmit:* *C* *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Neg *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Stable, simple shielding that is rarely moved. Subject to formal design review and controls (BRC, shielding control, key enable checklist) *(similar analysis to event 1e)*
6d.	**Radiant** Seismic event results in degradation of a hard X-ray beamline shielding	Seismic event Human error	**Engineered:** None **Administrative:** Beamline Review process, Training	**Engineered:** Radiation monitors (RSS) **Administrative:**	**Worker** *Unmit:* *B* *Mit:* C **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* IV	**Worker** *Unmit:* Low *Mit:* Neg **Public** *Unmit:* Neg *Mit:* Neg	Similar to 1f. Higher dose rate scenarios would involve very simple beam shielding components. Have equal probabilities and consequences. *(similar analysis to 1i)*

Event	Hazard Summary	Cause	Preventive Features	Mitigative Features	Consequence	Frequency	Risk	Comments
6e.	**Radiant** Facility flooded for several days	Excessive rainfall leads to flooding and release of radioactive materials.	**Engineered:** Site topography, facility location **Administrative:** None	**Engineered:** None **Administrative:** Emergency response	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* III	**Worker** *Unmit:* Neg *Mit:* Neg **Public** Unmit Neg *Mit:* Neg	No significant release is expected. The worst case scenario involves only a small amount of radioactive material (e.g., target inventory, sealed source inventory) exfiltration into water. Water damage would prevent equipment from operating and thereby remove most hazards.
6f.	**Radiant** High winds impact facility and cause a release	High Winds	**Engineered:** Building construction **Administrative:** None	**Engineered:** Concrete structure **Administrative:** Emergency response	**Worker** *Unmit:* C *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* III	**Worker** *Unmit:* Neg *Mit:* Neg **Public** Unmit Neg *Mit:* Neg	As noted for Event 5, the materials being handled are not susceptible to significant release under impact. The likely release in a collapse would be even less due to deposition in the rubble field.
EVENT 7: External Events								
7a.	**Radiant** Crane/ Vehicle Impact	Human error, equipment malfunction	**Engineered:** **Administrative:** Building construction, boom stops, barriers Training, Maintenance	**Engineered:** Concrete structure **Administrative:** Emergency Response	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* III *Mit:* III	**Worker** *Unmit:* Neg *Mit:* Neg **Public** Unmit Neg *Mit:* Neg	The worst case scenario involves only a small amount of radioactive material (e.g., target inventory, sealed source inventory) or solid PB resistant to impact release.
7b.	**Airplane Crash** Airplane crash impacts facility and releases radioactive material	Pilot error, plane malfunction	**Engineered:** None **Administrative:** None	**Engineered:** None **Administrative:** None	**Worker** *Unmit:* D *Mit:* D **Public** *Unmit:* D *Mit:* D	*Unmit:* IV *Mit:* IV	**Worker** *Unmit:* Neg *Mit:* Neg **Public** Unmit Neg *Mit:* Neg	The worst case scenario involves only a small amount of radioactive material (e.g., target inventory, sealed source inventory).

Twenty-six hazardous scenarios were evaluated. Five had an unmitigated risk of Moderate or High. The five events involved exposure of personnel to an operating beam. All twenty-six scenarios have a mitigated risk of Low or Negligible.

Eight controls were credited to obtain those results:

1. Beam Design – As previously stated.
2. Shielding – As previously stated.
3. Radiation Safety System (RSS)
4. Radiation Monitors (part of RSS)
5. Top-off Interlocks (part of RSS)
6. Search Procedure (Accelerator or Hutch)
7. Beamline Review Procedures
8. Procedure for Top-Off Qualification of Beamlines (part of Beamline Review Procedures)

These controls translate into five ASE entries as follows:

Table 4-6. Consolidated Set of Controls

#	ASE Entry	Controls
1	Electron Beam Parameter Limits	Beam Design
2	Radiation Shielding	Shielding
3	Engineered Safety Systems	Radiation Safety System (Including Radiation Monitors and Top-off Interlocks)
4	Access Control	Search Procedures
5	Beamline Review Process	Beamline Review Process (Including Procedure for Top-Off Qualification of Beamlines)

4.3 ACCIDENT ANALYSIS

4.3.1 Accident Selection

In the previous sections, various potential process-related, natural phenomena, and external hazards associated with the ALS were identified and described. Preventive and mitigative features for those hazards were identified and levels of risk were assigned. The accident analysis process begins by choosing those hazard events that may require more detailed analysis. The objective of the analysis is to assure that the engineered and administrative controls provide sufficient mitigation of both the hazard's consequence and likelihood in order to achieve a lower risk classification for the hazard. The results of the unmitigated hazard analysis were used as the basis for the selection of events. Those events with an unmitigated risk of "High" or "Moderate" are considered candidates for accident analysis.

In the hazard evaluation, it was shown that five scenarios had an unmitigated "High" or "Moderate" risk to the worker.

Three of these scenarios are for the accelerator:

1. Personnel exposure to neutron and bremsstrahlung radiation produced by electron beam (due to accelerator being occupied).
2. Electron beam mis-steer downstream of the defined safe point during Top-Off injection results in personnel exposure.
3. Electron beam mis-steer upstream of the defined safe point during Top-Off injection results in personnel exposure.

Two of these scenarios are for the synchrotron:

1. Personnel exposure to synchrotron radiation from a hard X-ray beam (due to the hutch being occupied)
2. Personnel exposure to synchrotron radiation from a hard X-ray beam (due to improper shielding)

There were no scenarios with an unmitigated "High" or "Moderate" risk to the public. The ALS facility generates activation levels well below other accelerators onsite. Qualitative evaluation alone indicates the milli- to –micro curie activation potential does not present a significant offsite risk, particularly when airborne release fractions from solid matrices on the order of 1 x 10^{-4} or less are considered.

4.4 POSTULATED ACCIDENTS

Accelerator and synchrotron operations present the most significant hazard in terms of radiation exposure. Without mitigation the consequences could be immediate and severe (category A). Note that shielding and beam design are initial conditions for acceptable normal operations and thus are always implicitly credited.

4.4.1 Personnel Exposure to Neutron and Bremsstrahlung Radiation Produced by Electron Beam (Due to Accelerator Being Occupied).

Exposure to prompt radiation from operation of the accelerator systems could occur if a person were inside the accelerator enclosures while the accelerators were operating. It is self-evident that any personnel in close proximity to the accelerator would receive a severe radiation injury. This risk is mitigated to acceptable levels by the Radiation Safety System (RSS) and the Search procedure.

The design philosophy behind the radiation safety system is that it must protect personnel from the significant hazards related to the operation of the linac, booster, transfer lines, storage ring, beamlines, and experimental areas. The RSS has redundant control of all specified systems and devices, such as rf, magnets, beam stops, etc. The RSS also has a system of interlocked, physical barriers to prevent personnel from entering hazardous areas. If these barriers are violated, hazardous equipment is turned off, and the sources of radiation are secured. Controlled access is achieved by locked gates at entrances to the parts of the ALS accelerator complex. All gates are provided with switches to indicate whether they are closed and latched. Opening of any gate in this area causes the shutdown of appropriate equipment. Each gate also has a key tree and a lighted sign to indicate the accelerator status. Each person entering under controlled access is required to take a key. The action of taking a key prevents operation of the accelerator, which cannot resume until all persons having keys have exited and returned their keys to the tree. Crash-off/search boxes in the accelerator enclosures are dual-function devices. If any "crash-off" box is activated, the radiation and large magnet power supplies are rendered safe by appropriate equipment shutdowns. Activation of the "search" portion of each box is part of the search procedure, which demands that a search be made of the area in a prescribed manner (and the boxes reset in a prescribed sequence) before hazardous equipment can be made operational once again.

The base engineering control that allows operation with acceptable worker and public doses is the permanent shielding (an initial condition). Proposed modifications to permanent shielding are governed by the shielding policy and require an extensive and thorough authorization process. In all cases, the shielding is sufficient to reduce the radiation at the site boundary to well below the DOE limit of 100 mrem/year and to assure that no areas outside the building, or general access areas inside the building such as offices have radiation levels above the same 100 mrem/year level.

4.4.2 Electron Beam Mis-steer During Top-Off Injection

Failure of a magnet causing electron beam mis-steering during Top-Off Injection would have the potential to cause high dose rates outside of the accelerator shielding. There are two possible scenarios resultant from a mis-steering. If an injected electron bunch were to travel past an identified safe point (typically one meter upstream from the storage ring concrete shielding wall), very high dose rates could be achieved. A second scenario involves the potential for repeated mis-steering upstream of this safe point. These risks are mitigated to an acceptable level by Top-Off interlocks, procedures for Top-Off qualification of beamlines, and radiation monitors that are part of the Radiation Safety System.

The personal safety shutter (PSS) for a beamline may be left open during Top-Off mode injection if that beamline is Top-Off mode qualified meaning it has followed the procedures for Top-Off qualification. A Top-Off mode qualified beamline meets the following requirements:

- A formal electron tracking analysis has been performed to identify any conditions under which an electron bunch might travel further than an established safe point on a beamline;
- Apertures used to calculate those above conditions are under formal configuration control; AND
- A combination of interlocks has been installed and tested to ensure safe operation of the Top-Off mode qualified beamline.

Prior to running Top-Off mode qualified beamlines in Top-Off mode, the required interlocks must be active. The shutter will be fail-safe and will be positively sensed in the closed position. The personnel safety shutter includes an 8-inch block of tungsten, which is designed to provide bremsstrahlung attenuation equivalent to the transition wall shielding. All of these controls preclude the potential for a mis-steer beyond the safe point.

A required component of the RSS are radiation monitors which are designed and placed to identify any mis-steering of injected electrons upstream of the safe point. Should they detect significant radiation levels, they will trip the interlocks thereby mitigating the second scenario.

4.4.3 Personnel Exposure to Synchrotron Radiation from a Hard X-ray Beam (Due to Hutch Being Occupied)

Exposure to prompt radiation from operation of the synchrotron could occur if a person were inside the beamline enclosure (hutch). It is self evident that personnel would receive a severe radiation injury. This risk is mitigated to acceptable levels by the RSS and the Search Procedure.

The design philosophy behind the RSS is that it must protect personnel from the significant hazards related to the operation of the linac, booster, transfer lines, storage ring, and beamlines. The RSS has totally redundant control of all specified systems and devices. The RSS also has a system of interlocked, physical barriers to prevent personnel from entering hazardous areas, in this case, the beamline hutches. If these barriers are violated, the hazardous equipment is turned off, and the sources of radiation are secured. The Search Procedure demands that a search be made of the hutches in a prescribed manner before hazardous equipment can be made operational once again.

The primary engineering control in place to protect the public for this hazard is the permanent shielding (an initial condition). Proposed modifications to permanent shielding are governed by the shielding policy and require an extensive and thorough authorization process. In all cases, the shielding is sufficient to reduce the radiation at the site boundary to well below the DOE limit of 100 mrem/year and to assure that no areas outside the building, or general access areas inside the building such as offices have radiation levels above the same 100 mrem/year level.

4.4.4 Personnel Exposure to Synchrotron Radiation from a Hard X-ray Beam (Due to Improper Shielding)

Exposure to synchrotron radiation can in principle occur for personnel in the beamline and experimental areas during operation of the accelerator. This risk is mitigated to acceptable levels by the Beamline Review Process and radiation monitors that are part of the RSS.

All elements of the accelerator facility are enclosed in concrete shielding supplemented with lead and polyethylene in critical locations. Beamlines are shielded in various ways. Beamlines are designed to contain the synchrotron radiation within the vacuum chamber and are protected by lead shielding in critical locations. Shielding is also used in certain cases where a significant flux of hard X-rays is present. Proposed modifications to permanent shielding are governed by the shielding policy and require an extensive and thorough authorization process. The ALS shielding is properly designed to limit occupational exposure to ALS staff.

The ALS beamline review procedures ensures that design errors are reviewed by the appropriate personnel, and that construction errors are detected through a thorough, documented commissioning process. If the beamline were not intact, either the photon shutter and the personnel safety shutter in the beamline front end would be shut by the ALS Floor Operator who is required to key off the beamline before providing access to the locks or tamper-proof seals on enclosures, or storage-ring operation would be halted by the protective interlock system. If the end station on hard X-ray beamlines were disassembled, the end-station personnel safety shutter would be shut by the protective interlock system or the ALS Floor Operator who provided the keys to allow disassembly would key off the beamline. Either case would automatically cause the personnel safety shutter to close.

4.4.5 A Release of the Inventory of Isotopes

In addition to the maximum credible incidents evaluated above, another accident scenario was evaluated for documentation purposes only. The ALS is authorized to handle various isotopes in various quantities at any one time. The additional accident scenario evaluates the release of a bounding inventory of these isotopes in a fire. The inventory of isotopes can be found in Appendix 4.

Consequences were calculated using the HOTSPOT code. A total of 0.983 Ci are present in the facility; the curies were assumed to be all from Pu-239. Results from HOTSPOT (Appendix 5) indicate a total a fire results in a dose consequence of 0.2 rem at 120 m. Additional details on the consequence calculations can be found in Appendix 4.

4.5 ANALYSIS SUMMARY AND CONCLUSIONS

Where compliance with existing federal regulations and available commercial standards alone may not provide adequate protection from the hazards associated with accelerator operations, the hazards were analyzed as discussed above. These analyses identified credible maximum bounding accident scenarios, and then the resulting consequences and probability of the event occurring were ascertained. The consequence and probability levels for each event were applied to a risk matrix shown in Table 4-3 that resulted in the risk rating determination for the event. Appropriate preventive, or mitigative controls, or both were identified to reduce the risks associated with each hazard. The cumulative effect of the controls described was conservatively estimated using professional safety judgment to reduce the mitigated risk to “Low” or “Negligible.”

Utilizing a ‘what-if’ analytical approach that included both direct radiation and those initiated by standard industrial hazards, a total of 27 accident scenarios were developed. Of these 5 had unmitigated risks that were unacceptable. The six scenarios relevant to control designation are summarized in Table 4-7.

Table 4-7. Risk Rating Summary

Accident	**Description**	**Initial Risk**	**Final Risk**
1a. Base Operation	Establishes initial requirements for routine operation.	Negligible	Negligible
1b. Accelerator access	Inadvertent personnel access to accelerator tunnels during periods of high radiation fields.	High	Low
1g. Beamline hutch access	Inadvertent personnel access to beamline hutches during periods of high radiation fields.	High	Low
1h. Beamline configuration	Inadvertent exposure to workers as result of mis-configuration of the beamline shielding.	High	Low
2c. Top-off failure (downstream from safe point)	Inadvertent exposure to workers at the beamlines as a result of an errant electron bunch travelling down the beamline.	High	Negligible
2d. Top-off failure (upstream)	Inadvertent exposure to workers at the beamlines as a result of an errant electron bunch travelling down the beamline.	Moderate	Negligible

The controls necessary to reduce each of these risks to acceptable levels are the credited controls. These are identified in Table 4-8. A complete listing of these credited controls is identified in Table 4-9, with references to the SAD sections where they are described. Additionally, this table identifies a noncredited control, minimum staffing, as this will be formally defied in the ASE. Table 4-10 presents the consolidated ASE specifications previously identified in Table 4-6.

Table 4-8. Credited Controls for Scenarios with Unacceptable Unmitigated Risk

Scenario ID	Scenario Description	Credited Controls
1a	Base Operation	Beam Design Shielding
1b	Accelerator access	Radiation Safety System (RSS) Search procedure
1g	Beamline hutch access	RSS Search procedure
1h	Beamline configuration	Beamline review process Radiation monitors (part of RSS)
2c	Top-off failure (downstream of safe point)	Top-off interlocks (part of RSS) Beamline top-off qualification procedure (part of Beamline review process)
2d	Top-off failure (upstream of safe point)	Radiation monitors (part of RSS) Beamline top-off qualification procedure (part of Beamline review process)

Table 4-9. List of Credited Controls

#	Control	Comments	Reference in Current SAD
1	Beam Design	Machine operating limits	Section 3.3.4 Pages 3-11 through 3-14
2	Shielding		Section 3.4.1 Pages 3-31 through 3-54
3	Radiation Safety System		Section 3.4.2 Pages 3-55 through 3-61
4	Radiation Monitors	Part of the RSS	Section 3.4.2 Pages 3-55 through 3-61
5	Top-off interlocks	Part of the RSS	Section 3.4.2.5 Page 3-61
6	Search procedures	Includes both Accelerator and Hutch	Section 3.4.2.2 Page 3-56
7	Beamline Review process		Sections 3.3.6 and 5.2.5 Pages 3-18 and 5-3
8	Top-off qualification for beamlines	Part of the Beamline Review process	Section 3.4.2.5 Page 3-61

Table 4-10. Consolidated Set of Controls

#	ASE Entry	Controls
1	Electron Beam Parameter Limits	Beam Design
2	Radiation Shielding	Shielding
3	Engineered Safety Systems	Radiation Safety System (Including Radiation Monitors and Top-off Interlocks)
4	Access Control	Search Procedures
5	Beamline Review Process	Beamline Review Process (Including Procedure for Top-Off Qualification of Beamlines)

SECTION 5. BASIS FOR ACCELERATOR SAFETY ENVELOPE

5.1 INTRODUCTION

Basic safety requirements that are applicable to the safe operation of the ALS are provided by Laboratory documents (e.g., the LBNL Pub-3000 Safety and health Manual), work authorization documents such as RWAs and AHDs, and ALS facility documents

Additional safety requirements that are focused specifically on accelerator safety are provided in the Accelerator Safety Envelope and the Operations Envelope.

The Accelerator Safety Envelope (ASE) defines the set of physical and administrative bounding conditions for safe operation of the ALS; the ASE is based on the engineered and administrative controls identified in the SAD as being necessary for the safe operation of the facility. The ASE is reviewed and approved by the DOE Berkeley Site Office (BSO). Any activity violating the ASE must be terminated immediately and DOE /BSO must be promptly notified of the violation and are treated as reportable occurrences.

The Operations Envelope (OE) specifies a set of controls that are selected by ALS facility management to assure that the conditions of the ASE are not exceeded. The OE is reviewed and approved by the ALS Division Deputy for Accelerator Development and Operations. Any violation of the OE must be promptly reported to ALS management.

The engineered and administrative controls addressed in the ASE and OE include the following :

- Electron Beam Parameter Limits
- Radiation Shielding
- Engineered Safety Systems
- Access Control
- Beamline Review Process

The controls are based on the hazards and controls identified in Section 4 *Safety Analysis.* These controls are described in Section 3.3 *Facility Description* and Section 3.4 *Radiation Protection System*.

5.2 CONTROLS

5.2.1 Electron Beam Parameter Limits

Beam parameter limits are necessary to prevent exceeding the shielding capability of the accelerator shielding. Without these controls, the radiation fields could exceed regulatory dose limits and institutional ALARA goals.

5.2.2 Radiation Shielding

The ALS Shielding Policy requires that shielding must be sufficient to reduce the radiation at the site boundary to well below the DOE limit of 100 mrem/year for members of the public and to reduce the radiation within the generally occupied areas of the building and surround environs to meet the targets of the ALS shielding policy (which are set well below the DOE occupational limits of 5 rem/year).

Permanent accelerator shielding is defined as the concrete shielding blocks, along with the associated lead and poly components that were installed during the construction and any subsequent additions to the ALS accelerator. All such shielding is subject to internal ALS configuration control processes. Any changes must be reviewed and approved by independent EHS staff. Procedures are in place to verify adequacy of any changes.

5.2.3 Engineered Safety Systems

The ALS designed and maintains a Radiation Safety System (RSS) to protect personnel from exposure to radiation above DOE limits. The RSS has redundant control of all specified systems and devices. Components of this system include interlocks (including top-off interlocks) and radiation monitors. The RSSs system of interlocked, physical barriers prevents personnel from entering hazardous areas. If these barriers are violated, hazardous equipment is turned off, and the sources of radiation are secured. Radiation monitors are designed and placed to identify any mis-steering of injected electrons upstream of the safe point. Should they detect significant radiation levels, they will trip the interlocks All components of the RSS meet specified levels of redundancy, independence, reliability, and fail-safe, and are subject to independent, technical reviews.

Configuration control of all parts of this system is governed by procedure. Work on this system is reviewed, and any changes must be authorized. Modifications are all documented and functionality tested before the system is returned to operation.

In addition, the system is subject to a comprehensive surveillance system to verify continuing effectiveness. Complete function tests are performed annually and to controlled procedures.

5.2.4 Access Control

Access controls inside the ALS facility assure that the radiation dose limits are not exceeded for facility personnel, experimenters, and laboratory personnel.

The Accelerator tunnels and Beamline Radiation Hutches have been identified as areas where High Radiation Areas may exist. In conjuction with the RSS, access to these areas is controlled through a search procedure. A search procedure is carried out for each of these areas prior to beam delivery to that area to ensure that all personnel are excluded. Before beam can be delivered into an accelerator tunnel or hutch, it must be searched and secured by qualified personnel following an area-specific search procedure.

5.2.5 Beamline Review Process

The ALS maintains a review process that ensures that all beamlines are reviewed to identify all potential beamline hazards and ensures that the hazards are properly mitigated. This review process encompasses necessary shielding requirements, required RSS components including personal safety shutters and radiation monitoring, and qualification for Top-Off operation.

The process is formalized through ALS procedures which identify required EHS Division review and approval. Included in this process is both initial design and on-going configuration control. Lastly, periodic surveillance is specified to ensure that all requirements remain in place and effective.

5.3 ACCELERATOR SAFETY ENVELOPE (ASE)

The Accelerator Safety Envelope is comprised of the six controls identified in Section 5.2, and is listed in Appendix 2.

5.4 OPERATIONS ENVELOPE

The ALS has developed a set of controls that are designed to assure that the requirements of the ASE are never violated. Though formally controlled through procedure, they are derived internally by ALS and subject only to internal division review and approvals. This set of controls defines the Accelerator Operations Envelope and is listed in Appendix 3.

SECTION 6. QUALITY ASSURANCE

The Advanced Light Source (ALS) Division at LBNL is responsible for the operation and development of the Accelerator. The operation and development of the facility are conducted in accordance with the LBNL Health and Safety manual PUB-3000, the LBNL ISM Plan and the ALS ISM Plan. The safety programs as outlined in these documents set forth the following 10 criteria:

6.1 PROGRAM (ORGANIZATION)

As outlined in section in PUB-3000, 'Line management and work leads are accountable for the protection of the public, the workers, and the environment. More specifically, laboratory line managers and work leads are responsible for integrating ES&H into work and for ensuring active, rigorous communication up and down the management line with the workforce.' Accordingly, the organization structure of the ALS is designed to place responsibilities for operational efficiency, safety, and quality in the hands of qualified personnel.

The details of the organizational structure, functional responsibilities, levels of authority, and interfaces for those managing, performing, and assessing work for the ALS facility are described in detail in Chapter 3 of this document.

6.2 TRAINING AND QUALIFICATION

LBNL policy states that "As a condition of employment, every employee, visiting scientist, student, or other person performing work at the Laboratory or at one of the Laboratory's off-site locations must be familiar with and implement applicable Laboratory safety standards. This responsibility includes taking the initiative to consult with resource groups when assistance or advice is needed to carry out operations safely." The ALS organization structure uses line management to ensure that Job Hazard Analysis (JHA) documents relevant to the work, activities, and operations are completed and that employees and guests receive the information to attend the required training courses or receive the necessary OJT (on the job training) and guidance needed to perform their work safely and efficiently. Training programs and requirements are reviewed annually and updated as needed. Using the JHA process, training requirements are tailored to the work which will be performed by the individual. For User experiments, before their work can be authorized, the training and qualification of each individual participating in the experiment is verified by the Beamline Scientist and EHS Program Manager.

6.3 QUALITY IMPROVEMENT

Periodic LBNL internal peer reviews are conducted within LBNL and in addition ALS conducts periodic division internal self-assessments of all the research groups including the ALS facility in an effort to minimize safety hazards, to identify potential problems and to ensure compliance to the required safety standards. Equipment failures are reviewed and, if required, changes in maintenance schedules, operating procedures and designs are made to reduce recurrence.

At the ALS, several effective activity-level feedback and improvement processes are being implemented, including daily user interface with beamline scientists, user satisfaction surveys, a formal lessons learned process for activities controlled by work permits, weekly accelerator operations critique meetings, shutdown and maintenance plans that address lessons learned, and surveillance procedures that contain specific requirements to perform activity-level feedback. In addition, ALS has developed a rigorous supervisor walkthrough checklist that specifically addresses ISM, including questions on each ISM core function, JHAs, the ALS Experiment Safety Sheets, and ALS operations policy/practices/personnel. ALS documents results of supervisor walkarounds in a database identifying safe and unsafe acts and assigns trend codes for unsafe acts.

To strengthen our communication of safety information (besides using email and the internet), the ALS Division Safety Committee (DSC) members meet once a month to share safety information and discuss safety issues or concerns. Lessons Learned (from within LBNL and from outside) and Roundtable Discussions are standing agenda items of these monthly meetings. Most importantly, the DSC includes ALS Safety Circles leads whose mission is to pass safety information to and from their safety circles. A Lessons Learned bulletin board is soon to be up on the wall at Building 6. Reports of Lessons Learned cases will be posted, along with color photos and a display case housing some examples of Lessons Learned items such as frayed and burned cables, to provide a visual alert/reminder of safety to the ALS Community.

6.4 DOCUMENTS AND RECORDS

The ALS prepares and maintains log books for all accelerator-related operations. All user experiments are documented through the Experiment Safety Sheet (ESS) process which is maintained and archived. Maintenance records and repairs conducted for accelerator equipment are maintained by the accelerator operations group. Training records are documented by the Environmental, Health & Safety Division, which maintains an easily accessible web based database. Surveillance, maintenance, and calibration activities for safety-related systems are recorded by the responsible engineering support group.

6.5 WORK PROCESS CONTROL

The ALS work process is a coordinated effort between the engineering support groups and the operation groups to ensure that the standard technical practices adopted by LBNL, ALS and the industrial oversight agencies (OSHA, NFPA, CA, etc.) are followed. The training of the technicians and the engineering support staff is designed to provide sufficient knowledge of related safety issues and best practices for safe operation and maintenance of accelerator and beamline equipment and systems. The Integrated Safety Management core functions and guidelines are utilized to develop work agendas. The planning and implementation of maintenance for equipment and system is an example of where a graded approach is followed that best utilizes the resources and capabilities of the support staff.

Work planning is governed by an approved work process control procedure.

6.6 DESIGN

Facility modifications and equipment designs are reviewed by the appropriate technical review committees and authorized by appropriate management. These processes are controlled and documented through formal ALS procedures.

6.7 PROCUREMENT

Purchase requests are submitted through the LBNL procurement system. All purchases are reviewed for safety issues. Detailed specification documents are prepared for major equipment purchases. The LBNL Acquisition Management System evaluates potential vendors and evaluates bids on major purchases.

6.8 INSPECTION AND ACCEPTANCE TESTING

Fabricated items are inspected to ensure the as-built item meets the tolerances specified on engineering drawings. Procured items are tested to ensure they meet specifications. On-going, formal systems are in place to assure configuration control over credited safety systems.

6.9 ASSESSMENT

To assure that the overall ES&H systems at the ALS are robust and effective, the ALS has implemented a systematic assessment approach that is matched to the needs of a large-scale user facility. For convenience, we group the assessments into categories. Process-driven assessments are those required by higher tier documents and are proceduralized to some extent. Operational assessments derive directly from the mission statement in trying to help the user staff perform their science in a safe manner. They have both an assistance and an oversight function. As with other divisions, supervisor walkthroughs are an integral component as is the annual self-assessment. These two are designed to be complementary with supervisor walkthroughs concentrated on work practices and the self-assessments concentrated on work environment.

Following is a list and short discussion of these assessment functions:

- <u>Process-Driven Assessment</u>—This is being performed by procedure as part of facility-based or institutional requirements. Examples are interlocks tests, projects that might extend beyond the Accelerator Safety Envelope, and Beamline reviews. Other examples are AHD or RWA-driven inspections.

- <u>Operational Assessment</u>—Another type of assessment can be categorized as operational. Examples of these are the function of the Floor Operators. Their positions implement radiation safety for the beamlines. They are radiological workers on the ALS RWA and are charged with maintaining configuration control of the beamlines. They spend a large part of each shift walking by each beamline as a part of this verification.

- <u>Supervisor Assessment</u>—At the ALS, first-line supervisors spend a significant part of each day in the field working with their staff and evaluation of safety is integrated into this process. Second-level and higher supervisors have gone through ALS specific training in performing effective safety walkthroughs. These are focused on work activities of their staff as opposed to physical inspections of the space.

- <u>Annual Self Assessment</u>—The safety circle teams form QUEST (Quality ES&H Self-Assessment Teamwork) inspection teams and perform assessment on issues that are of interest to the ALS; these are internally driven criteria. The other component is evaluation of the institutional criteria. Along with this is an evaluation of the goals from the previous year's self assessment. A report is drafted and circulated first to the ALS Division Safety Committee and then to management for review and approval.

- <u>Independent Assessment</u>—In addition to internal assurance functions, ALS participates fully in independent institutional assurance activities, such as MESH (Triennial Management of Environment, Safety and Health Assessment) and TAP (Technical Assurance Program).

6.10 INDEPENDENT ASSESSMENT

The LBNL Accelerator Safety Review Committee reviews accelerator operations whenever significant modifications are made to the facility or mode of operation. Safety assessments are also conducted by LBNL and outside agencies (DOE, OSHA, etc.).

SECTION 7. ENVIRONMENTAL MONITORING PROGRAM

7.1 ENVIRONMENTAL COMPLIANCE

ALS operations adhere to DOE orders and to federal, state, and local regulations applicable to environmental protection. DOE orders applicable to activities with potential environmental consequences include 450.1 Environmental Protection Program [DOE, 2003a] 5400.5 Radiation Protection of the Public and the Environment, 435.1 Radioactive Waste Management [DOE, 2001a], 231.1A Environment, Safety and Health Reporting [DOE, 2004a], and 420.2B Safety of Accelerator Facilities [DOE, 2004b].

7.1.1 National Environmental Policy Act (NEPA) Compliance Program

ALS activities are subject to the requirements of the National Environmental Policy Act (NEPA) in accordance with DOE Order 451.1B National Environmental Policy Act Compliance Program. Environmental studies and documentation for the ALS are complete. The principal environmental documents are the Environmental Assessment [DOE, 1989] and the Findings of No Significant Impact.

The original ALS project scope assumed that significant portions of the then existing 184-Inch Cyclotron and its shielding would be reused. LBNL prepared an environmental evaluation of the original project, which resulted in a June 1987 DOE-SF Memorandum to File [Neely 1987] stating that the project has “clearly insignificant impact.”

In October 1987, decommissioning and removal of the 184-Inch Cyclotron was authorized. In an April 1988 memorandum, DOE/EH-1 requested that an environmental assessment (EA) be prepared for the project. The EH-1 memorandum cited the increased project scope and a lack of depth in the earlier LBNL environmental evaluation as the bases for the request. An EA was prepared and received S-1 concurrence and EH-1 approval. A Finding of No Significant Impact was issued in August 1989 [Brush, 1989].

A subsequent minor project change added a cooling tower, chiller plant, and associated piping to the project scope. This modification was found to have insignificant impact, and Memorandum to File on the change was issued in September 1990 [Decker, 1990].

7.1.2 Prevention of Significant Deterioration (PSD)

The ALS is located in the San Francisco Bay Area Air Basin, which is considered by the U.S. Environmental Protection Agency (EPA) to be an attainment area for nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). The EPA has not yet classified the air basin with respect to suspended particulate matter less than 10 microns in diameter (PM10). Emissions of NO_2 and SO_2 from the ALS would be generated primarily by fuel combustion (e.g., in boiler operation). These emissions would not cause PSD threshold levels established by the Bay Area Air Quality Management District (BAAQMD) to be exceeded and, therefore, would not trigger PSD review requirements by the BAAQMD.

7.1.3 California Clean Air Act

To conform with the California Clean Air Act (CCCA), the BAAQMD has revised its new source-review rules to achieve the goal of "no net increase" in emissions of nonattainment pollutants. The BAAQMD requires: (1) emission offsets if emissions of organic compounds, nitrogen oxides, or PM10 exceed the threshold amounts and (2) the best available control technology (BACT) for sources that emit criteria pollutants in excess of threshold amounts. The ALS will not result in the emission of any criteria pollutants in excess of threshold amounts that would trigger emission-offset or BACT requirements.

7.1.4 National Pollutant Discharge Elimination Systems (NPDES)

In accordance with the Federal Clean Water Act, Berkeley Lab has held a California General Industrial Storm Water Permit since 1992. This permit applies to the entire site and includes requirements that address plans and documents, monitoring inspections, employee training, an annual report, and best management practices to protect the quality and minimize the quantity of stormwater released from the Lab site.

7.1.5 National Emission Standard of Hazardous Air Pollutants (NESHAP)

Radionuclides released to the atmosphere for ALS research activities must adhere to NESAHP regulations. The ALS handles a variety of radionuclides and can generate a number of radioactive air-activation products due to accelerator activities. Potential environmental releases

are evaluated and reported annually to the Environmental Protection Agency. Copies of historical reports can be found at the following website:
http://www.lbl.gov/EH&S/esg/tableforreports/tableforreports.htm

7.1.6 DOE Environmental Orders 450.1, 435.1, and 5400.5

DOE Order 450.1, Environmental Protection Program, established a requirement that LBNL must implement an Environmental Management System (EMS) and that the EMS must be integrated with existing Integrated Safety Management (ISM) systems. The EMS focuses on improving environmental performance in 3 general areas: 1) preventing pollution, 2) minimizing waste and 3) conserving resources. This goal has been incorporated into the EH&S Self-Assessment process.

DOE Orders 450.1, 5400.5 and external regulations (above), contain requirements for environmental monitoring programs, including: (1) sampling of workplace and effluent air in all areas where significant quantities of radionuclides are handled, (2) continuous monitoring of penetrating radiation at three perimeter stations, one offsite station and in each major accelerator complex, (3) sampling of wastewater discharges at 2 perimeter stations for radionuclides, organic chemicals and metals, (4) on-site and off-site ambient air sampling for radionuclides, (5) sampling of rainfall for tritium, and (6) groundwater sampling for organic chemicals, metals and tritium.

DOE Order 435.1 contains the requirement for preparing an annual Site Environmental Report. Copies of past reports may be obtained at the following website:
http://www.lbl.gov/EH&S/esg/tableforreports/tableforreports.htm

7.2 EXISTING PERMITS

Copies of environmental permits are available at the following website: http://www.lbl.gov/EH&S/esg/permitfortable/operatingpermitstable.html.

7.2.1 Air Emissions

Generally, the Bay Area Air Quality Management District exempts research activities, such as laboratory hoods and vacuum systems, from needing operating permits authorizing the activity. But any activity, research or support, may require an operating permit if the chemical-specific threshold quantities are emitted into the air during a set period of time. The BAAQMD has issued permits to Berkeley Lab for such activities such as wipe cleaning using solvents, spray paint booths, emergency generators, fuel dispensing and soil vapor extraction systems. The wipe cleaning permit is issued for activities across the entire site. The ALS support operation is one of the groups that tracks monthly solvent usage for wipe cleaning activities. One or more of Berkeley Lab's permitted emergency generators serves the ALS buildings.

Above and beyond operating permits, all activities are expected to adhere to standards of operations that are found in BAAQMD's Rules and Regulations:
http://www.baaqmd.gov/dst/regulations/index.asp

7.2.2 Water Consumption

The State of California currently does not require permits for water consumption.

7.2.3 Wastewater Discharge

The East May Municipal Utility District (EBMUD) has issued a site-wide wastewater discharge permit that would also cover the ALS. The ALS will not generate wastewater streams that would require additional pretreatment and, consequently, associated pretreatment permits from EBMUD.

7.2.4 Storm Water Discharge

Berkeley Lab's stormwater releases are permitted under the California-wide Industrial Activities Storm Water General Permit. As required by this permit, the Laboratory has implemented a Storm Water Pollution Prevention Plan that includes measures to prevent the release of contaminants into the storm water system.

7.2.5 Hazardous Waste Generation and Discharge

Hazardous waste generated at the ALS will be handled and disposed of in accordance with California EPA hazardous waste regulations and with LBNL procedures for hazardous waste, as described in the Guidelines for Generators of Hazardous Chemical Waste at LBNL and Guidelines for Generators of Radioactive and Mixed Waste at LBNL Small quantities of hazardous wastes will be stored at satellite accumulation areas at the ALS at the various points of waste generation. Storage quantities at the ALS satellite waste-accumulation areas will not exceed LBNL (and regulatory) limits. Following LBNL procedures, waste will periodically be transferred from satellite accumulation areas to the LBNL Hazardous Waste Handling Facility (HWHF). Permits are not required by the state or the EPA for satellite accumulation areas. LBNL is in the process of renewing its permit from the California EPA to operate the HWHF.

7.2.6 Underground Tanks

There will be no underground tanks constructed as part of the ALS.

SECTION 8. DECOMMISSIONING AND DECONTAMINATION PLAN

The life of the ALS will be 20 years or longer. Chemicals and other hazardous materials will be similar to those of other general laboratory facilities. Operation of the ALS will produce small quantities of long-lived radioactive products over its lifetime. The ALS is primarily a soft X-ray/EUV storage ring and produces very small amounts of induced activity in components chronologically impacted by the beam. A detailed D&D plan will be written when the facility is declared excess.

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SECTION 10. APPENDICES

Appendix 1: Operational Procedures

Appendix 2: ALS Accelerator Safety Envelope

Appendix 3: ALS Accelerator Operations Envelope

Appendix 4: Consequences for Release of Inventory of Radioactive Material

Appendix 5: Calculations for Release

APPENDIX 1: OPERATIONAL PROCEDURES

The controlled versions of all ALS operational procedures are maintained on a website. To find the current version, go to the following URL:

http://alsintra.lbl.gov/procedures/index.htm

APPENDIX 2: ALS ACCELERATOR SAFETY ENVELOPE (ASE)

Lawrence Berkeley National Laboratory

Accelerator Safety Envelope (ASE) for the Advanced Light Source *(Rev. 7)*

Updated
November 23, 2009

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Signature Page for Rev. 7 of the ALS ASE

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1. INTRODUCTION

The Advanced Light Source (ALS) Accelerator Safety Envelope (ASE) defines the set of physical and administrative boundary conditions for safe operation. The ASE is based on the analysis described in the ALS Safety Assessment Document (SAD). It describes the engineered and administrative controls that limit the risk of the operation and experimentation to acceptable levels. The ASE limits on the electron beam characteristics are based on design considerations and operational limitations necessary for safe operation of the facility. Variations in the operating conditions are permitted if and only if their extent, duration and consequences do not exceed the bounds imposed by the ASE. An accelerator facility operating within its ASE can experience unplanned events, such as an unscheduled power outage, that may interrupt its operation but do not compromise the safety of the facility. The ASE should not be violated by the effects of such unscheduled, but anticipated, events of no EH&S consequence. Variations beyond the boundaries of the ASE are treated as reportable occurrences as defined in DOE Order 231.1a Occurrence Reporting and Processing of Operations Information.

The basis for the ASE presented here is the safety analysis described in Sections 4 and 5 of the SAD for the ALS. The requirements specified in the ASE are binding for the operation of the ALS. Significant revisions of these requirements, changes in operating conditions, or any facility and/or equipment modification that involve an unreviewed EH&S issue will require a revision or supplement to this ASE/SAD. The ASE covers both technical and administrative matters. Requirements in the ASE related to administrative matters include those that are important in establishing safe operating conditions in the facility. Nothing in the ASE will restrict changes in organizational titles or organizational assignments within these requirements if equivalent functions are provided.

2. ALS ASE

The engineered and administrative controls addressed in the ASE are summarized in Table 2.1. These controls are based on the hazards and controls identified in Section 4 *Safety Analysis* in the SAD.

Table 2-1. Credited Controls

(1)	Electron Beam Parameter Limits: i. Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of <0.85 W. ii. Booster synchrotron beam power: any combination of beam current, electron energy, and cycle rate that gives a beam power of <8.25 W. iii. Energy in storage-ring beam: any combination of stored current and electron energy that gives a total energy of < 1 kJ. In addition, the energy of the electron beam is limited to 1.96 GeV, and the current of the electron beam is limited to 800 mA.
(2)	Radiation Shielding Electron beam delivery is restricted to the Accelerator tunnels which have permanent shielding in place to reduce the external radiation fields to safe levels. Permanent shielding is maintained and controlled by the ALS shielding policy.
(3)	Engineered Safety Systems Access to the Accelerator tunnels and Beamline Radiation Hutches is controlled through the Radiation Safety System (RSS) to prevent personnel access while the beam is present. Components of this system include top-off interlocks and radiation monitors.
(4)	Access Control A search procedure is also carried out for Accelerator tunnels and Beamline Radiation Hutches prior to beam delivery to that area to ensure that all personnel are excluded.
(5)	Beamline Review Process A Beamline Review process is implemented, which includes beamline shielding qualification and configuration control, requirements for beamline RSS, and qualification of beamlines for Top-Off operation.

3. DISCUSSION OF CONTROLS

3.1 Electron Beam Parameter Limits

Beam parameter limits are necessary to prevent exceeding the shielding capability of the accelerator shielding. Without these controls, the radiation fields could exceed regulatory dose limits and institutional ALARA goals.

3.2 Radiation Shielding

The ALS Shielding Policy requires that shielding must be sufficient to reduce the radiation at the site boundary to well below the DOE limit of 100 mrem/year for members of the public and to reduce the radiation within the generally occupied areas of the building and surround environs to meet the targets of the ALS shielding policy (which are set well below the DOE occupational limits of 5 rem/year).

Permanent accelerator shielding is defined as the concrete shielding blocks, along with the associated lead and poly components that were installed during the construction and any subsequent additions to the ALS accelerator. All such shielding is subject to internal ALS configuration control processes. Any changes must be reviewed and approved by independent EHS staff. Procedures are in place to verify adequacy of any changes.

3.3 Engineered Safety Systems

The ALS designed and maintains a Radiation Safety System (RSS) to protect personnel from exposure to radiation above DOE limits. The level of protection provided and the system's reliability were designed to be appropriate for the hazards anticipated and to prevent negligent behavior of users. The RSS has redundant control of all specified systems and devices. Components of this system include interlocks (including top-off interlocks), and radiation monitors. The RSSs system of interlocked, physical barriers prevents personnel from entering hazardous areas. If these barriers are violated, hazardous equipment is turned off, and the sources of radiation are secured. Radiation monitors are designed and placed to identify any mis-steering of injected electrons upstream of the safe point. Should they detect significant radiation levels, they will trip the interlocks. All components of the RSS meet specified levels of redundancy, independence, reliability, and fail-safe, and are subject to independent, technical reviews.

Configuration control of all parts of this system is governed by procedure. Work on this system is reviewed, and any changes must be authorized. Modifications are all documented and functionality tested before the system is returned to operation.

In addition, the system is subject to a comprehensive surveillance system to verify continuing effectiveness. Complete function tests are performed annually and to controlled procedures.

3.4 Access Control

Access controls inside the ALS facility assure that the radiation dose limits are not exceeded for facility personnel, experimenters, and laboratory personnel.

The Accelerator tunnels and Beamline Radiation Hutches have been identified as areas where High Radiation Areas may exist. In conjunction with the RSS, access to these areas is controlled through a search procedure. A search- procedure is carried out for each of these areas prior to beam delivery to that area to ensure that all personnel are excluded. Before beam can be delivered into an accelerator tunnel or hutch, it must be searched and secured by qualified personnel following an area-specific search procedure.

3.5 Beamline Review Process

The ALS maintains a review process that ensures that all beamlines are reviewed to identify all potential beamline hazards and ensures that the hazards are properly mitigated. This review process encompasses necessary shielding requirements, required RSS components including personal safety shutters and radiation monitoring, and qualification for Top-Off operation.

The process is formalized through ALS procedures which identify required EHS Division review and approval. Included in this process is both initial design and on-going configuration control. Lastly, periodic surveillance is specified to ensure that all requirements remain in place and effective.

4. ASE VIOLATIONS

Occurrence of any of the following conditions constitutes a violation of the ASE limitations and requires shutdown of appropriate facility activities:

- Exceeding the beam parameters described in Table 2-1.
- Systemic failure of the Accelerator shielding control process.
  Note: Individual incidents will be evaluated through USI to determine if there is an overall failure of the process.
- Delivery of beam into an occupied Accelerator Tunnel or Beamline Radiation Hutch.
- Systemic radiation safety failure of the Beamline Review Process.
  Note: Individual incidents will be evaluated through USI to determine if there is an overall failure of the process.

5 EMERGENCY ACTIONS

Emergency actions may be taken that depart from the ASE provided that: (1) an emergency situation exists and (2) no action consistent with the ASE can provide adequate or equivalent protection. Such emergency actions will be authorized by the Operator-in-Charge or his designee and performed by personnel trained and qualified for the equipment or system requiring action. If emergency action is taken, both verbal notification and a written report will be made within 24 hours to the BSO Site Manager.

APPENDIX 3: ALS ACCELERATOR OPERATIONS ENVELOPE

- Linac beam power: any combination of beam current, energy, and cycle rate that gives a beam power of 0.30 W.
- Booster energy will not exceed the limits of 40 MeV to 1.9 GeV
- Booster current will not exceed 16 mA.
- Storage ring energy will be from 1 to 1.9 GeV.
- Storage ring current will not exceed 550 mA.
- At least one qualified operator is on shift during accelerator operation. On-shift is defined to mean present and available at the Facility.
- Magnetic-field and rf/microwave-radiation intensities comply with Threshold Limit Values (TLVs) established by the American Conference of Government Industrial Hygienists.
- Operations is guided by the ALS Accelerator Conduct of Operations and references therein.
- All entrances to the ALS experimental-area floor are locked and posted as a Controlled Area; access is restricted to authorized personnel.
- The integrity of the accelerator and safety systems is verified by inspection tours and by adherence to maintenance schedules, as specified in Operational Procedures.
- The requirements of the Beamlines Operations Envelope and the Experiments Operations Envelope are met.
- Repetition rate of the booster will not exceed 1 Hz.

APPENDIX 4: CONSEQUENCES FOR ADDITIONAL ACCIDENT SCENARIO

In addition to the maximum credible incidents evaluated in Sections 4.3.3 and 4.3.4, another accident scenario was evaluated for information only. The additional scenario considers the release (via fire) of the entire inventory of radioactive isotopes found in the Table A4-1.

Table A4-1. Bounding Isotope Inventory

Radionuclide	Total radionuclide possession limit for the ALS in mCi
Am-241	5.532E+01
Am-243	4.005E+01
Cm-243	1.000E-01
Cm-246	6.014E-01
Cm-248	2.964E-01
Eu-152	4.000E-01
Eu-154	1.000E-02
H-3	1.000E-01
I-129	2.000E-05
Np-237	1.500E+00
Pu-238	8.504E+01
Pu-239	1.229E+02
Pu-240	4.820E+00
Pu-241	6.570E+02
Pu-242	5.001E+00
Sr-90	5.000E+00
Tc-99	1.200E-01
Th-232	3.418E-01
U-233	1.000E+00
U-235	1.060E-02
U-238	3.212E+00

The radiological consequences of the accident scenarios involving the release of radioactive materials were calculated using the HOTSPOT code, version 2.06[1]. The HOTSPOT code was developed by LLNL for the Nonproliferation, Arms Control, and International Security (NAI) Program as a quick response tool for estimating radiological impacts resulting from the accidental release of radioactive material.

[1] S.G. Homann, Lawrence Livermore National Laboratory, *Health Physics Codes for the PC*, HOTSPOT, Health Physics Codes for the PC.

The HOTSPOT code consists of a series of mathematical models that represent the radioactive material immediately after release from its source, movement of the material as it disperses downwind of the facility, deposition of the radioactive material on the ground, and the effects of the airborne and deposited material on man and the environment.

The HOTSPOT code uses a Gaussian plume to model atmospheric dispersion. The material released is evenly distributed over the length of the plume, and any distance from the release point can be chosen as the dose point.

The plume release height was assumed to be 0 m, representing a ground level release. The receptor height was assumed to be at 1.5 m.

Weather conditions used were Class F atmospheric stability (very stable, minimal turbulence and mixing) and 1 m/s wind speed, with no rainfall. These conditions tend to maximize the dose in most cases.

The dose calculations were evaluated at 120 m which is the distance from the 88-Inch Cyclotron facility to the nearest site boundary.

The doses that appear in the HOTSPOT output are based on information from Federal Guidance Report No. 13[2].

The following parameters were used as in input into HOTSPOT:

Table A4-2. Parameters Used in the HOTSPOT Release Analysis.

Parameter	Value
Release height	0 m
Receptor height	1.5 m
Atmospheric stability	“F” stability
Wind speed	1 m/s
Distance to offsite dose point	120 m

Results from HOTSPOT indicate a total effective dose of 0.2 rem at the site boundary (120 m). Appendix 5 contains the HOTSPOT runs.

[2] U. S. Environmental Protection Agency, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report No. 13 Report No. EPA 402-R-99-001, 1999.

APPENDIX 5: HOTSPOT RUNS

```
Hotspot  Version 2.06 General Fire
Apr 14, 2009 03:12 PM

Source Material            : Pu-239  S   24065y
Source Term                : 9.8300E-01 Ci
Airborne Fraction          : 1.00E-02
Respirable Fraction        : 5.00E-02
Respirable Release Fraction: 5.00E-04
Release Radius             : 1 m
Cloud Top                  : 0.00 m
Physical Height of Fire    : 0 m
Effective Release Height   : 0.00 m
Wind Speed (h=10 m)        : 1.0 m/s
Distance Coordinates       : All distances are on the Plume Centerline
Stability Class            : F
Respirable Dep. Vel.       : 0.30 cm/s
Non-respirable Dep. Vel.   : 8.00 cm/s
Receptor Height            : 1.5 m
Inversion Layer Height     :  None
Sample Time                : 10.000 min
Breathing Rate             : 3.33E-04 m3/sec

TEDE includes              : Inhalation dose + Submersion
Maximum Dose Distance      : 0.018 km
MAXIMUM TEDE               : 0.983 rem
Inner  Contour Dose        : 1.0 rem
Middle Contour Dose        : 0.500 rem
Outer  Contour Dose        : 0.100 rem
Exceeds Inner  Dose Out To : Not Exceeded
Exceeds Middle Dose Out To : 0.064 km
Exceeds Outer  Dose Out To : 0.17 km

FGR-13 Dose Conversion Data
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DISTANCE km	T E D E (rem)	TIME-INTEGRATED AIR CONCENTRATION (Ci-sec)/m3	GROUND SURFACE DEPOSITION (uCi/m2)	GROUND SHINE DOSE RATE (rem/hr)	ARRIVAL TIME (hour:min)
0.100	2.7E-01	1.4E-05	5.4E-02	2.0E-10	00:04
0.120	2.0E-01	1.0E-05	3.7E-02	1.4E-10	00:04
0.200	7.8E-02	3.9E-06	1.3E-02	4.9E-11	00:08
0.300	3.4E-02	1.7E-06	5.5E-03	2.1E-11	00:12
0.400	1.9E-02	9.5E-07	2.9E-03	1.1E-11	00:16
0.500	1.2E-02	5.9E-07	1.8E-03	6.8E-12	00:20
0.600	7.8E-03	4.0E-07	1.2E-03	4.6E-12	00:24
0.700	5.6E-03	2.8E-07	8.6E-04	3.3E-12	00:28
0.800	4.2E-03	2.1E-07	6.5E-04	2.4E-12	00:32
0.900	3.3E-03	1.7E-07	5.0E-04	1.9E-12	00:36